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TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY

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Conducted by
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With the Co-operation of Eminent Investigators

CONTENTS

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VOLUME 37 MARCH, 1932 NO. 1

TERRESTRIAL-MAGNETIC ACTIVITY AND ITS RELATIONS TO SOLAR PHENOMENA

BY J. BARTELS

Abstract—A homogeneous series of monthly means of terrestrial-magnetic activity for the years 1872 to 1930 is derived and extended backward, in annual means, to 1835. The annual variation of magnetic activity and of the relative sunspot-numbers is discussed by means of new tests for periods. Only the semi-annual wave in magnetic activity is recognized as physically significant. Its maxima prefer the times when the Sun is in the celestial equator, and not, as has been suggested, the times when the Sun's axis is most inclined towards the ecliptic. This view is supported by tests using the harmonic dial and the probable-error circle, and several independent considerations.

The close relations between sunspot-numbers and terrestrial-magnetic activity in the annual and monthly means are discussed. Some general statistical aspects are given for the treatment of the correlation between such series with after-effects, for which both solar activity and terrestrial-magnetic activity are typical. The homogeneity of the whole available series for relative sunspot-numbers and for areas of sunspots and faculae is tested; some inhomogeneities are found, apart from a general lag of terrestrial-magnetic activity that has occurred in some sunspot-cycles. A break in the homogeneity of the international magnetic character-figures in recent years is discovered.

The individual 27-day recurrences in terrestrial-magnetic activity during 1906-31, and their relations to solar activity are discussed with the help of a graphical day-by-day record. They indicate the existence of persistent active areas on the Sun's surface, called *M*-regions, which, in many cases, cannot be coordinated to such solar phenomena as are observable by direct astrophysical methods. This holds in particular for the new solar indices which are available for the years 1928-30, and which are found so closely correlated to sunspot-numbers, that they fail to improve the correlation between solar activity and terrestrial-magnetic activity. Observations of terrestrial-magnetic activity yield therefore not only information about geophysical influences of such solar phenomena that may be traced in astrophysical observations, but supplement these direct observations themselves.

CONTENTS

1—*Introduction*

Among the geophysical phenomena which have been investigated with regard to solar influences of other kind than the regular diurnal and seasonal variations, terrestrial magnetism stands out as yielding the most consistent and reliable relationships[1]. The derivation of a new long and homogeneous series for terrestrial-magnetic activity, which will comprise the first part of this paper, justifies the reconsideration of some of these relationships that have often been treated with less satisfactory material. The statistical aspects will be emphasized, since the relationship is of a statistical nature inasmuch as each observed solar phenomenon seems to produce a geophysical effect only with a certain probability, and since all geophysical theories either grow out of statistical results, or must be subjected to statistical tests. The methods described in this paper may be used to test other relationships, such as those supposed in meteorology or in wireless transmission-phenomena. It will appear that caution is necessary in dealing with short series of observations, taken over intervals of a few years only. This holds especially for the recent years 1928-30, in which the trend in the direct solar observations differs conspicuously from the trend in terrestrial-magnetic activity, in contrast to the fairly high correlations found in the greatest part of the series since 1872.

2—*Magnetic activity, as expressed by the international magnetic character-figures and other measures*

Terrestrial-magnetic activity at a given station, and in a certain interval, may be defined as an expression for the frequency and intensity of magnetic disturbances in that interval. There are many ways in which this general definition may be expressed as a numerical measure. *Characterization*, the simplest, is now widely used. In this measure every observatory assigns, from the character of its photographic records, to each interval of 24 hours, between successive Greenwich midnights, a character-figure, "0" for quiet, "1" for moderately disturbed, and "2" for greatly disturbed days. The average for all collaborating observa-

[1] The geophysical effects of solar phenomena have been summarized by the author in Ergebnisse der exakten Naturw., **9**, 37-78 (Berlin 1930).

tories (the number of which increased from 30 to about 45, since this measure was begun in 1906) is the international magnetic character-figure[2] *C*.

The values of *C* represent the fluctuations of activity from day to day very satisfactorily and have been used with advantage in selecting the international quiet and disturbed days. They also have been used in several investigations such as those of C. Chree and J. M. Stagg[3] on the 27-day recurrence phenomenon, which is due to the rotation of the Sun, and in L. W. Pollak's periodogram-analysis[4]; they will be used for similar purposes in §§ 17 and 18.

Because of the complexity of the disturbance-phenomenon and its different appearance at equatorial and polar stations, Ad. Schmidt[5] advocates the practice of leaving the assignment of the character-figures more or less to the subjective judgment of the observer in charge at the observatory (though, of course, certain model curves might be selected at each station as guiding examples) and not to give strict prescriptions based on actual measurements. He agrees that the characteristics of magnetic disturbance, such as shift in the mean value, the magnitude, derivation, number of the single oscillations, etc., are so numerous, that the establishment of an objective value for the activity of each single day could be gained only by very elaborate investigations. The time and labor spent in this work would be quite out of proportion to the result, since this characterization of a single day, or of another interval of time, would be, in any case, only statistically significant, without furthering essentially a physical explanation. On the other hand, just because of this limited importance of the characterization, the simple procedure adopted for the international character-figures serves its purpose, namely, *the relative comparison of the magnetic activity on successive days within, say, three months to a year.* That on so many days practically all observatories report character "0", and, during great magnetic storms, all report "2", proves not only the well-known world-wide nature of magnetic activity, but also the satisfactoriness of this method to derive *C*.

There are, however, as Schmidt points out, certain limitations in the use of the average international character-figures *C*. As stated when comparing activities on two days close together, we may use the values of *C* with confidence. Thus, we may accept as about equally disturbed April 1 and 18, 1910, since on both these days $C = 1.3$, and may regard April 12, 1910, with $C = 1.0$, as less disturbed than the other two days, but we should hesitate to say that the magnetic activities on April 12, 1930, with $C = 1.3$, or April 15, 1930, with $C = 1.0$, were equivalent to those for the days in April 1910. For, although the arranged international values of *C* are the same, there is no safeguard that the standard of characterization may not have shifted within the 20 years from 1910 to 1930. There are several reasons for such shifts: (*a*) Change of ob-

[2] Published by the Royal Meteorological Institute of the Netherlands, and reprinted annually in this JOURNAL.

[3] Phil. Trans. R. Soc., A, **227**, 21-62 (1927).

[4] Prager Geophysikalische Studien, 3 [Čechoslovakische Statistik Bd. 64 (1930)]; reviewed in Terr. Mag., **36**, 110 (1931); also Naturw., **18**, 343-349 (1930). The results of this valuable paper are outside the scope of this paper and will therefore not be discussed here, though an application of the methods described in §§ 9 and 10 would seem promising.

[5] Report Internat. Met. Committee, Berlin Meeting 1910, p. 93 (London Met. Off., 1912). See Schmidt's discussion of the character-figures, Met. Zs., **33**, 481-492 (1916).

server—for instance, an observer who is used to polar records will judge tropical records mostly as quiet; (*b*) shift of standard for the same observer—for instance, an observer during a sunspot-minimum (as 1923) and therefore accustomed to quiet curves may assign the character-figure 2 to records of a type to which in a disturbed year (as 1917) during a sunspot-maximum, when he is, so to say, hardened by the frequency of disturbances, he would assign the figure 1; (*c*) systematic change in the method of characterization—this has actually occurred in recent years, since several observatories have introduced numerical measures for estimating the character, as described in the De Bilt circulars for 1923 and 1924; and (*d*) establishment or discontinuation of collaborating observatories.

As will be seen later (§ 13), such shifts have occurred (though, fortunately, less frequently than might have been expected). *An objective measure of activity is therefore needed for establishing a homogeneous series for all the time since consistent terrestrial-magnetic observations were begun.* It will be sufficient, for the time being, to devise such a measure only as averages for intervals of months or years, since C is available for the relative characterization of days within a month.

3—*The u-measure of activity; monthly means 1872 to 1930*

There has been chosen as such a measure the *interdiurnal variability*, U, that is, the average difference, regardless of sign, between successive daily means of the magnetic horizontal intensity. Referring to former papers[6, 7, 8] in which U and its relations to other measures of activitity have been discussed, a short summary of its main properties will be sufficient.

Each magnetic disturbance affects systematically the daily average of the magnetic field-vector[9]. This phenomenon, commonly called post-perturbation (Nachstörung), most pronounced in the horizontal component H or in the north component X, is one of the most regular phenomena in terrestrial magnetism[10]. Figure 1 shows, for an interval chosen at random, consecutive averages over 24-hourly intervals, centered at 0^h, 6^h, 12^h, and 18^h, Greenwich mean time, of X or of H, for three widely separated observatories, namely, Seddin (near Potsdam, Germany), Huancayo (Peru), Watheroo (Western Australia). The three curves are strikingly similar, showing the typical depression of H or of X during a disturbance and the gradual recovery to normal value afterwards. Obviously, a measure, such as U, derived from these systematic changes of H or of X, at some observatories, must represent the world-wide part of magnetic activities in a suitable way.

Figure 1 has also a bearing on field-observations. Judging from the curve for Huancayo, measurements in tropical South America throughout 24 hours on the quiet day November 5, 1928, would be expected to give a daily mean value for horizontal intensity that is about 50γ lower than the value, at the same station, on the quiet day November 9. Post-

[6] Ad. Schmidt, Ergebnisse der erdmagnetischen Beobachtungen in Potsdam und Seddin im Jahre 1921, 6 ff. (1924).

[7] J. Bartels, Met. Zs., **40**, 301-305 (1923); **42**, 147-152 (1925); Archiv des Erdmagnetismus, Heft 5 [Berlin, Abh. Met. Inst., **8**, No. 2 (1925)].

[8] W. van Bemmelen, Met. Zs., **42**, 143-147 (1925).

[9] See stereogram 7, Terr. Mag., **36**, 194 (1931).

[10] J. A. Brown, Trans. R. Soc. Edinburgh, **22**, Part 3 (1861). W. van Bemmelen, Met. Zs., **12**, 321-329 (1895). Ad. Schmidt, Zs. Geophysik, **1**, 9-13 (1924-25).

perturbations should, therefore, be taken into account in the derivation of secular variation from field-observations.

The practical computation of this activity-measure is done as follows: From the ordinary daily means of *H* or of *X*, whichever may be published in the observatory's year-book, consecutive differences from day to day are formed. We assign to each day the difference of its mean from that of the preceding day; in this way the greater differences which occur in the

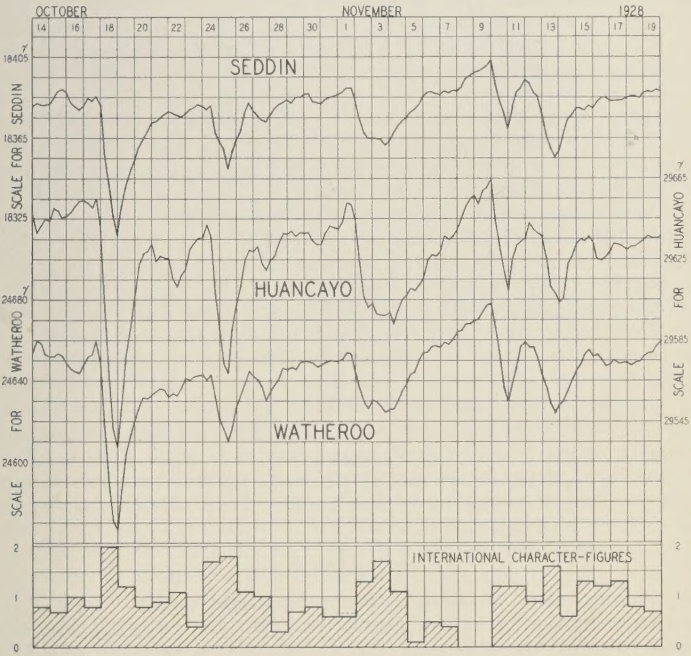


FIG. 1—The world-wide nature of post-perturbation indicated by similarity of three curves showing the daily means magnetic north component at Seddin (Germany) and horizontal intensity at Huancayo (Peru) and at Watheroo (Western Australia), October 14 to November 19, 1928 (Plotted means for consecutive 24-hour periods, 6 hours apart; those for 24 hours centered at Greenwich midnight coincide with vertical lines)

transitions from a quiet to a disturbed day are ascribed to the latter. Monthly means of these differences, taken regardless of sign, are formed to the nearest tenth of a gamma ($1\gamma = 0.00001$ c. g. s.). Thus the mean for July, for instance, is the average of 31 differences, the first being the change of *H* from June 30 to July 1—that is, the mean value for July 1 minus the mean value for June 30—and the last being the change from July 30 to July 31.

A singular difficulty arises in all numerical measures of magnetic activity due to occasional failure to obtain complete photographic records; such losses occur mostly during great disturbances, when the recording light-spot either leaves the photographic paper, or moves so

fast as to leave no trace. Only a few observatories (among those whose records are used in this paper, Potsdam, Bombay, and Batavia) have effective safeguards to insure continuity of their records, but after the stations for the International Polar Year of 1932-33 will have been equipped with special insensitive magnetographs there is hope for a change in the philosophical attitude of those stations which so frequently lose records in the most interesting intervals of the history of terrestrial magnetism. In any case, it is not possible simply to ignore these losses in deducing an average measure of activity, since this would lead to a gross underestimate. For cases when records were lost at an observatory because of magnetic storms, no attempt was made in this discussion to interpolate and no monthly mean was deduced for that observatory for that particular month; when, however, the loss of trace occurred during quiet times, interpolation with the help of other stations was often possible and was applied, provided the monthly mean difference could thereby be obtained within an accuracy of one or two per cent.

The next step is the combination of the results from a number of observatories in order to obtain an expression of the magnetic activity for the Earth as a whole, that is, a universal value for each month. To a fair degree of approximation, the post-perturbation can be regarded[10] as a uniform magnetic field, say P, varying in time, but always parallel to the Earth's magnetic axis (for which we take the direction from the Earth's center to a point in 78°.5 north, 291° east of Greenwich). Suppose, for a certain observatory, the interdiurnal variability, U, of H or of X, has been determined as described; the angle, in space, between the directions of H or of X and of the magnetic axis is easily calculated, and may be called β. If then the variability of H or of X were due only to changes in P, it would register these changes only in the ratio $\cos\beta:1$. Therefore, the interdiurnal variability of P based upon U determined from an observatory's records would be

$$u = U/\cos\beta \qquad (1)$$

If, for the moment, we designate the magnetic equator as the great circle perpendicular to the magnetic axis, we may, slightly idealizing, call u the *interdiurnal variability of the horizontal component at the magnetic equator.*

From the value U measuring the interdiurnal variability of the north component X at Seddin (near Potsdam), for instance, we obtain, therefore, with $\beta = 55°.0$

$$u = 1.745\,U \qquad (1a)$$

U as well as u will be expressed in units of 10γ ($=0.0001$ c. g. s. unit), in order to make u of the order of magnitude 1, and therefore comparable with the character-figures. This relation (1a) was used in order to calculate, from the Seddin records alone, a preliminary value of u, say, u_S. This is the only application made of formula (1); the values U obtained from the records of the other observatories were reduced to the standard of u_S in the following way. There is now a total of 114 months for which we have data from both Seddin and Watheroo, from which U_S and U_W may be determined. The sum of the 114 monthly means of the unrevised measure $u = 1.745\ U_S$, expressed in the unit 10γ is 104.07, while the sum of the 114 means of U_W for the same months is 79.81 in the same unit.

If, therefore, each monthly mean for U_W is multiplied by the conversion-factor $k = 104.07/79.81 = 1.30$, we get from the Watheroo data a second series of preliminary monthly means for u, say u_W. According to the method of calculation, u_W is connected with u_S only insofar as, for all months in which the interdiurnal variability is available for both stations Seddin and Watheroo, the mean average of u_W is equal to that of u_S. This standardizing does not bias then fluctuations of u_W and u_S from month to month, in which we are alone interested, serving only to guarantee the homogeneity of the series of u. U depends to some extent on the choice of the 24-hourly interval (for instance, 0^h to 0^h, or 1^h to 1^h, etc.) for which the daily means are formed, and therefore the conversion-factors k must be determined separately for each group of years in which the observatory adhered to the same method of forming daily means; a new discussion of the physical significance[7] of this influence of the beginning of the day will, however, be postponed for the present, since the daily variation of activity will not be discussed in this paper.

Records of the following observatories were used (L denotes the limit of the 24-hourly intervals used for the daily means in Greenwich mean time):

Seddin (52°.3 N, 13°0 E), 1905-28; X with $L = 0^h.0$; values of U for 1905-23 are published[7] and those for 1924-28 were computed from the daily means of X as given in the year-books.

Potsdam (52°.4 N, 13°.1 E), 1891-1904; H with $L = 23^h.6$; values of U are published[7].

Greenwich (51°.5 N, 0°.0), 1872-90; H, astronomical reckoning is used through 1884 with $L = 12^h.0$, and civil reckoning with $L = 0^h.0$ thereafter. The Greenwich series was used to provide an extra-tropical station for the years before the establishment of the Potsdam Observatory. The unusual form in which the early Greenwich observations are published caused some inconvenience. Daily means for the disturbed days are not published, but had to be computed, which was done by selecting and averaging about 96 values nearest to each quarter of an hour. Up to 1882, no correction had been applied for temperature; use of the uncorrected values would be expected to yield somewhat higher values for U than the corrected values, but several tests showed that the systematic difference is negligible—less than one per cent. The published daily means are expressed in parts of the horizontal intensity H; the reduction of the Greenwich series to the Bombay standard (which is derived, to a high degree of accuracy, from the Seddin standard) does not require knowledge of H for Greenwich, but in order to obtain a comparable expression for the reduction-factor k the mean H was taken as 18040γ. On the whole, the resulting value of u_G from the old Greenwich series appears to be less reliable than the Bombay series, probably because of shifts in the base-line, which are comparatively more dangerous in higher latitudes where the interdiurnal variability itself is smaller. Therefore, Greenwich values were only given half weight in the formation of the final means for u.

Bombay (18°.6 N, 72°.9 E), 1872-1927; from 1872-1920 a homogeneous series for U has been published by N. A. F. Moos in his famous discussions of the Bombay observations[11] and has been used in the

[11] Magnetic observations made at the Government Observatory, Bombay (Colaba magnetic data), 1846 to 1905, Part 2, p. 456 (1910); continued in the later volumes for 1906-10, 1910-15, and 1916-20.

former papers [7]. However, since it was found that a few monthly means for U at Bombay were affected by loss of records, the relative weight of these particular monthly means was made one-half. Through 1920, H-values are given with $L = 5^h.1$; after 1921, frequent changes occurred, L being $19^h.0$, $19^h.1$, and $0^h.0$ for 1921-24, 1925-26, and 1927, respectively.

Batavia-Buitenzorg (6°.6 S, 106°.8 E), 1884-99, 1902-26; H from 1884-99 with $L = 17^h.4$; X from 1902-19 with $L = 17^h.4$, and from 1920-26 with $L = 17^h.0$.

Honolulu (21°.3 N, 201°.9 E), 1902-30; H hourly values from 1902-14 with $L = 11^h.0$, and from 1915-30 with $L = 11^h.0$.

Porto Rico (18°.2 N, 294°.6 E), 1902-16; H from 1902-14 with $L = 4^h.9$, and from 1915-16 with $L = 4^h.0$.

Tucson (32°.2 N, 249°.2 E), 1917-30; H with $L = 7^h.0$. (The daily mean values of H for Honolulu and Tucson through 1930 were kindly furnished prior to publication, by the United States Coast and Geodetic Survey, Washington, D. C.)

Watheroo (30°.3 S, 115°.2 E), 1919-30; H with $L = 16^h.0$.

In Table 1 the conversion-factors k are given as computed for the three usual seasonal groups of months, in order to show how the ratios of the interdiurnal variabilities vary with season. For the actual computation, however, only the values of k derived from *all* months have been used. The stability of these values for k for each homogeneous

TABLE 1—*Values of conversion-factor k*

Station	Years	Nov. Dec. Jan. Feb.	Mar. Apr. Sep. Oct.	May June July Aug.	All months	Station	Years	Nov. Dec. Jan. Feb.	Mar. Apr. Sep. Oct.	May June July Aug.	All months
Seddin.....	1905–1928	1.745	1.745	1.745	**1.745**	Batavia...	1884–1890	.....	.....	.....	**1.05**
Potsdam...	1891–1904	1.67	1.67	1.67	**1.67**	Batavia...	1891–1899	1.04	0.99	1.11	**1.05**
Greenwich..	1872–1882	1.19	1.37	1.21	**1.25**	Batavia...	1902–1920	1.01	1.06	1.20	**1.09**
Greenwich..	1883–1890	1.20	1.39	1.34	**1.31**	Batavia...	1921–1926	1.06	1.09	1.16	**1.10**
Bombay....	1872–1890	.....	.....	.....	**0.96**	Honolulu..	1902–1916	1.16	1.12	1.16	**1.15**
Bombay....	1891–1899	0.98	0.92	1.03	**0.97**	Honolulu..	1917–1928	1.17	1.11	1.15	**1.14**
Bombay....	1900–1910	0.93	0.93	1.01	**0.96**	Honolulu..	1929–1930	.....	.....	.....	**1.14**
Bombay....	1911–1920	0.96	0.92	1.00	**0.96**	Porto Rico	1903–1916	1.28	1.18	1.21	**1.22**
Bombay....	1921–1924	1.01	1.01	1.08	**1.03**	Tucson....	1917–1928	1.44	1.42	1.47	**1.44**
Bombay....	1925–1926	0.97	0.98	1.05	**0.995**	Tucson....	1929–1930	.....	.....	.....	**1.44**
Bombay....	1927	0.85	0.90	0.99	**0.91**	Watheroo..	1919–1928	1.26	1.27	1.38	**1.30**
						Watheroo..	1929–1930	.....	.....	.....	**1.30**

series is remarkable—thus, for example, as long as Bombay did not alter the manner of deriving daily means, k was always 0.96, so that it was safe enough to take this value also for the period before 1891, where no direct comparison with Potsdam or Seddin is possible. Similar considerations lead to extrapolated values of k for Batavia (1884-90) and for Honolulu, Tucson, and Watheroo (1929-30). The low value of k for Greenwich, determined by comparison with Bombay, indicates spurious variations in Greenwich and is the main argument for assigning one-half weight to the Greenwich values, as mentioned above. The preliminary

TABLE 2—*Revised monthly means, u_1-measure, 1872-1930*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
....	....	....	....	....	....	....	....	....	....	....	....	....	....	1901	0.46	0.45	0.64	0.41	0.44	0.56	0.54	0.50	0.44	0.44	0.46	0.54	0.49
1872	1.09	1.90	1.42	1.23	1.13	1.17	1.75	2.14	1.45	1.92	1.32	1.02	1.46	1902	0.42	0.52	0.45	0.61	0.48	0.46	0.51	0.56	0.42	0.56	0.60	0.40	0.50
1873	1.41	0.88	1.49	1.25	0.79	0.96	0.78	0.90	0.77	0.77	1.04	0.79	0.99	1903	0.44	0.57	0.44	0.79	0.53	0.50	0.59	0.77	0.61	1.68	1.34	1.09	0.78
1874	0.99	1.29	1.20	1.28	0.71	0.72	0.82	0.80	0.82	1.39	0.80	0.62	0.95	1904	0.89	0.46	0.47	1.00	0.90	0.86	0.56	0.68	0.61	0.72	0.79	0.63	0.71
1875	0.66	1.09	0.86	0.77	0.72	0.65	0.65	0.55	0.86	0.69	0.70	0.49	0.72	1905	0.72	0.88	0.96	0.68	0.52	0.78	0.72	0.93	0.94	0.78	1.43	0.86	0.85
1876	0.57	0.86	0.78	0.53	0.49	0.59	0.54	0.51	0.61	0.56	0.61	0.57	0.60	1906	0.53	1.08	0.70	0.68	0.88	0.70	0.78	0.69	0.70	0.50	0.75	1.07	0.76
1877	0.67	0.61	0.62	0.51	0.86	0.72	0.58	0.67	0.59	0.72	0.82	0.57	0.66	1907	0.79	1.73	0.91	0.62	0.92	0.79	0.80	0.63	1.04	1.01	1.08	0.67	0.92
1878	0.70	0.46	0.43	0.54	0.50	0.79	0.48	0.56	0.68	0.59	0.56	0.73	0.58	1908	0.70	0.63	1.04	0.82	0.91	0.61	0.81	1.00	2.11	0.96	1.14	0.90	0.97
1879	0.43	0.49	0.62	0.55	0.64	0.85	0.50	0.53	0.74	0.60	0.52	0.70	0.60	1909	1.10	0.79	1.12	0.62	1.31	0.67	0.71	0.68	1.94	1.16	0.78	0.94	0.98
1880	0.52	0.40	0.67	0.74	0.63	0.62	0.73	1.38	0.97	0.82	1.11	0.89	0.79	1910	0.68	0.64	1.10	1.08	0.79	0.63	0.58	1.17	0.68	1.02	0.62	0.69	0.81
1881	0.87	1.14	0.78	0.75	0.62	0.70	0.83	0.71	1.20	0.87	1.19	0.78	0.87	1911	0.53	0.54	0.70	0.78	0.89	0.60	0.66	0.59	0.61	0.69	0.53	0.85	0.66
1882	0.72	0.92	0.76	2.16	0.84	0.90	0.99	0.94	0.72	1.82	2.95	0.88	1.22	1912	0.46	0.46	0.55	0.67	0.53	0.45	0.57	0.63	0.64	0.55	0.75	0.47	0.56
1883	0.54	0.86	1.07	1.10	0.71	0.80	0.88	0.81	1.31	0.78	1.41	0.79	0.92	1913	0.54	0.48	0.51	0.56	0.45	0.46	0.38	0.45	0.54	0.58	0.39	0.41	0.48
1884	0.92	0.86	0.79	0.94	0.82	0.94	1.05	0.65	1.01	1.14	1.29	0.84	0.94	1914	0.46	0.49	0.45	0.73	0.54	0.47	0.68	0.50	0.77	0.67	0.66	0.60	0.58
1885	0.91	0.90	1.04	0.91	1.15	0.94	0.91	0.79	0.96	0.70	0.83	0.75	0.90	1915	0.59	0.70	0.80	0.78	0.57	1.30	0.74	0.66	0.82	1.37	1.19	0.87	0.87
1886	1.13	0.68	0.93	0.89	0.94	0.64	0.88	0.76	0.73	0.82	0.89	0.52	0.82	1916	0.76	0.59	1.42	1.22	0.84	0.79	0.73	1.37	0.95	0.94	0.71	0.54	0.90
1887	0.56	0.56	0.60	0.84	0.70	0.69	0.80	0.80	0.85	0.64	0.70	0.84	0.72	1917	1.12	0.87	0.85	1.03	0.84	1.08	1.33	2.37	1.04	1.20	0.83	1.06	1.14
1888	1.09	0.44	0.69	0.67	0.89	0.65	0.59	0.76	0.59	0.72	0.65	0.64	0.70	1918	0.74	1.23	1.21	1.49	1.05	0.92	0.75	1.11	1.06	1.51	1.21	1.54	1.15
1889	0.56	0.57	0.73	0.55	0.65	0.79	0.53	0.58	0.76	0.58	0.86	0.60	0.65	1919	1.01	1.04	1.22	0.97	1.52	1.00	0.91	1.47	1.64	1.55	1.32	1.10	1.23
1890	0.48	0.51	0.49	0.48	0.55	0.54	0.47	0.48	0.67	0.88	0.79	0.44	0.56	1920	0.84	1.00	2.54	1.20	1.11	0.85	0.90	1.03	1.32	0.99	0.92	0.94	1.14
1891	0.62	0.77	0.81	0.86	0.89	0.57	0.92	0.90	1.14	0.72	0.84	0.92	0.83	1921	0.69	0.83	0.90	1.13	2.70	0.80	0.64	0.76	0.77	0.92	0.88	0.75	0.98
1892	0.98	1.70	1.66	1.13	1.71	1.39	1.61	1.68	0.86	0.83	1.17	1.25	1.33	1922	0.74	0.85	1.09	0.80	0.67	0.63	0.60	0.61	0.99	0.76	0.54	0.54	0.74
1893	0.90	1.18	1.00	0.90	0.73	1.10	0.80	1.60	1.07	1.09	1.07	0.89	1.03	1923	0.60	0.68	0.80	0.51	0.63	0.64	0.68	0.56	0.83	0.77	0.70	0.51	0.66
1894	0.83	1.73	1.44	1.41	0.92	1.16	1.67	1.85	1.22	0.84	1.39	0.77	1.27	1924	0.83	0.57	0.57	0.55	0.98	1.00	0.70	0.54	0.87	0.78	0.91	0.56	0.74
1895	0.88	1.43	0.96	0.91	0.62	0.85	0.87	0.78	0.99	1.13	1.00	0.76	0.93	1925	0.64	0.72	0.66	0.62	0.92	0.78	0.70	0.84	1.14	1.12	0.84	1.08	0.84
1986	0.81	0.84	1.07	0.76	1.24	0.77	0.77	0.97	0.94	0.77	0.80	0.84	0.88	1926	1.41	1.41	1.34	1.43	0.89	1.12	0.78	0.76	1.45	1.73	0.84	1.03	1.18
1897	1.10	0.79	0.75	1.04	0.77	0.69	0.75	0.61	0.66	0.69	0.63	1.13	0.80	1927	1.08	0.84	1.15	1.37	1.00	0.63	0.88	1.05	0.70	1.59	0.83	0.95	1.01
1898	0.54	0.69	1.18	0.71	0.69	0.67	0.57	0.69	1.54	0.75	0.84	0.73	0.80	1928	0.58	0.58	0.83	0.64	1.26	0.78	1.79	1.01	1.27	1.38	1.02	0.72	0.99
1899	0.63	0.97	0.70	0.60	0.86	0.58	0.53	0.64	0.56	0.46	0.44	0.50	0.62	1929	0.84	1.50	1.66	0.82	0.85	0.80	0.99	1.01	0.89	1.00	1.01	1.21	1.05
1900	0.70	0.63	1.20	0.52	1.06	0.42	0.43	0.53	0.48	0.56	0.40	0.42	0.61	1930	0.79	0.82	0.88	0.84	1.13	1.01	0.70	0.77	1.43	1.31	1.01	1.25	1.00

2

values of the magnetic activity u for all other observatories, however, were averaged with equal weight when deriving the final value of u given for each month in Table 2. The values for Sitka, derived in a former paper[7], are not included since the discussion had shown that the interdiurnal variability of H at polar stations is not so exclusively governed by the world-wide post-perturbation vector as at the non-polar stations. (The discussion of magnetic activity in polar regions will be postponed till the results of the International Polar Year 1932-33 will be available.) The number of available observatories was 2 from 1872 to 1883, 3 from 1884 to 1899, 2 from 1900 to 1901 (this interval of the reorganization of the Batavia Observatory fell fortunately in a period of low magnetic activity, so that the average of Potsdam and Bombay is sufficient), 4 for 1902, 5 from 1903 to 1918, 6 from 1919 to 1926, 5 for 1927, 4 for 1928, and 3 for 1929 and 1930. The series is based on more than 80,000 single changes from day to day.

4—*Annual means of activity since 1834*

More for illustration than for actual use, the series was extended backward to 1835. Before 1872, no satisfactory data for the calculation of interdiurnal variabilities are available. It was, therefore, necessary for these years to use measures derived from the diurnal variation. The chief drawback[7] of such measures is the great change of the diurnal magnetic variation, and all its characteristics, with season; indeed, one of the chief advantages of the u-measure is its comparative freedom from this seasonal influence which is not easily eliminated. Therefore, it was not attempted to derive monthly means prior to 1872, but only annual means, centered at the beginning and in the middle of each year; thus the mean entered for 1836.0 is the average of the twelve months July 1835 to June 1836, that entered for 1836.5 is for January to December 1836.

Early records of magnetic observatories before 1872 are available, but are lacking in uniformity of procedure; many stations did not observe on Sundays. Only two fairly homogeneous series of observations before 1872 were found. One of them, the "Einheitliche Deklinations-Variationen" of R. Wolf and A. Wolfer [12], which we call E, is fairly homogeneous back to 1835.0; it is chiefly deduced from the daily range of the declination as observed in Greenwich at certain fixed hours. The other series available since 1847.5, for the "summed ranges" s, is due to Moos[13]; s is derived from the mean diurnal variation of H at Bombay for each single month, expressed in departures from the average, and is the sum of these departures, summed without regard to sign. The standardization was done as follows: For the annual means 1872-1901, the values of u and s have the high correlation-coefficient $+0.94$ and stand in the linear relation (derived by least-square adjustment)

$$u = 0.0040\ (s - 82) \tag{2}$$

Preliminary annual values of u were calculated from this formula for 1847-72; comparison with E, for the same years, gave correlation-coefficient $+0.83$, and the linear relation

$$u = 0.164\ (E - 3.54) \tag{3}$$

[12] Astr. Mitt, Nr. 61, 11 ff., contains a table of E for the years 1781 to 1880.
[13] Colaba magnetic data 1846 to 1905, Part 2, pp. 294 and 691 (1910).

This formula was used to calculate a second preliminary series for u from 1835 to 1872. The two series, deduced from s and from E, were then combined to give final values for u; starting with 1847.5 where the series from s begins, the values deduced from s were given double weight relative to those deduced from E. The values in Table 3 and Figure 2 may be regarded as homogeneous, but it is understood that they are least reliable for 1835 to 1847, better for 1847.5 to 1872.0, and satis-

TABLE 3—*Revised annual means, u-measure, 1835-1930*

Mean epoch	u	Mean epoch	u	Mean epoch	u	Mean epoch	u	Mean epoch	u
....	......	1851.0	0.92	1871.0	1.70	1891.0	0.69	1911.0	0.73
....	......	1851.5	0.90	1871.5	1.60	1891.5	0.83	1911.5	0.66
....	......	1852.0	0.82	1872.0	1.47	1892.0	1.17	1912.0	0.59
....	......	1852.5	0.76	1872.5	1.46	1892.5	1.33	1912.5	0.56
....	......	1853.0	0.76	1873.0	1.36	1893.0	1.10	1913.0	0.55
....	......	1853.5	0.78	1873.5	0.99	1893.5	1.03	1913.5	0.48
....	......	1854.0	0.76	1874.0	0.94	1894.0	1.17	1914.0	0.49
....	......	1854.5	0.66	1874.5	0.95	1894.5	1.27	1914.5	0.58
1835.0	1.02	1855.0	0.60	1875.0	0.83	1895.0	1.20	1915.0	0.72
1835.5	1.16	1855.5	0.58	1875.5	0.72	1895.5	0.93	1915.5	0.87
1836.0	1.39	1856.0	0.59	1876.0	0.65	1896.0	0.84	1916.0	0.94
1836.5	1.63	1856.5	0.66	1876.5	0.60	1896.5	0.88	1916.5	0.90
1837.0	1.72	1857.0	0.71	1877.0	0.62	1897.0	0.85	1917.0	0.92
1837.5	1.60	1857.5	0.70	1877.5	0.66	1897.5	0.80	1917.5	1.14
1838.0	1.64	1858.0	0.89	1878.0	0.61	1898.0	0.83	1918.0	1.21
1838.5	1.68	1858.5	1.06	1878.5	0.58	1898.5	0.80	1918.5	1.15
1839.0	1.43	1859.0	1.28	1879.0	0.60	1899.0	0.79	1919.0	1.16
1839.5	1.40	1859.5	1.43	1879.5	0.60	1899.5	0.62	1919.5	1.23
1840.0	1.40	1860.0	1.42	1880.0	0.60	1900.0	0.64	1920.0	1.29
1840.5	1.22	1860.5	1.35	1880.5	0.79	1900.5	0.61	1920.5	1.14
1841.0	1.11	1861.0	1.30	1881.0	0.90	1901.0	0.48	1921.0	1.10
1841.5	1.01	1861.5	1.22	1881.5	0.87	1901.5	0.49	1921.5	0.98
1842.0	0.90	1862.0	1.10	1882.0	0.99	1902.0	0.49	1922.0	0.79
1842.5	0.90	1862.5	1.00	1882.5	1.22	1902.5	0.50	1922.5	0.74
1843.0	0.90	1863.0	0.98	1883.0	1.12	1903.0	0.53	1923.0	0.66
1843.5	0.89	1863.5	0.94	1883.5	0.92	1903.5	0.78	1923.5	0.66
1844.0	0.86	1864.0	0.89	1884.0	0.94	1904.0	0.89	1924.0	0.71
1844.5	0.85	1864.5	0.84	1884.5	0.94	1904.5	0.71	1924.5	0.74
1845.0	0.86	1865.0	0.83	1885.0	0.99	1905.0	0.71	1925.0	0.73
1845.5	0.95	1865.5	0.79	1885.5	0.90	1905.5	0.85	1925.5	0.84
1846.0	1.06	1866.0	0.76	1886.0	0.85	1906.0	0.85	1926.0	1.11
1846.5	1.01	1866.5	0.73	1886.5	0.82	1906.5	0.76	1926.5	1.18
1847.0	0.97	1867.0	0.67	1887.0	0.71	1907.0	0.85	1927.0	1.05
1847.5	1.14	1867.5	0.68	1887.5	0.72	1907.5	0.92	1927.5	1.01
1848.0	1.33	1868.0	0.74	1888.0	0.76	1908.0	0.83	1928.0	0.89
1848.5	1.31	1868.5	0.81	1888.5	0.70	1908.5	0.97	1928.5	0.99
1849.0	1.36	1869.0	0.98	1889.0	0.65	1909.0	1.04	1929.0	1.14
1849.5	1.20	1869.5	1.11	1889.5	0.65	1909.5	0.98	1929.5	1.05
1850.0	1.03	1870.0	1.36	1890.0	0.58	1910.0	0.93	1930.0	0.96
1850.5	0.99	1870.5	1.67	1890.5	0.56	1910.5	0.81	1930.5	1.00

NOTE—The value entered for 1835.0 is the mean for the 12 months July 1834 to June 1835, that for 1835.5 is the mean for the 12 months January to December 1835, etc.

factory for 1872.5 to 1930.5. In Figure 2, u is plotted together with the relative sunspot-number R to show the 11-years' cycle in both. Figure 3 shows the monthly means of u and of R from 1900-30.

5 *Activity and energy of disturbance*

If X, Y, Z are the rectangular components of the magnetic force, the magnetic energy of the field is equal to the volume-integral of $(X^2+Y^2+Z^2)/8\pi$, taken throughout the field. If the field changes from (X^0, Y_0, Z_0) to $(X_0+\triangle X_0,\ Y_0+\triangle Y_0,\ Z+\triangle Z_0)$, the magnetic energy increases by the integral of

(4) $2\,(X_0\triangle X_0+Y_0\triangle Y_0+Z_0\triangle Z_0)/8\pi+(\triangle X_0^2+\triangle Y_0^2+\triangle Z_0^2)/8\pi$

S. Chapman[14] called the first term "joint-energy integral" of the disturbance; since the variations $(\triangle X,\ \triangle Y,\ \triangle Z)$ are usually small compared with the average values $(X_0,\ Y_0,\ Z_0)$, the second term, called "self-energy integral," is generally negligible in comparison with the first. All measures of magnetic activity which involve squares of the ranges of the magnetic elements, such as the measure proposed by F. Bidlingmaier, take into account only the small "self-energy" and are therefore in no way real measures of the energy of disturbance.

The measure proposed by A. Crichton Mitchell, and adopted by the International Geophysical Union[15] is $X_0R_X+Y_0R_Y+Z_0R_Z$, where X_0, Y_0, Z_0 are the mean values of the components, and R_X, R_Y, R_Z are the absolute ranges, that is, differences between the highest and lowest values of X, Y, Z, respectively, in the course of a Greenwich day. The form of this measure reminds one of that of the joint-energy integral but this similarity is, of course, deceptive, since the extreme values of X, with range R_X, occur generally at other times than the extreme values of Y and Z. Therefore, whatever the merits of these various measures of activity may be, they certainly cannot be regarded as more significant than others in a physical aspect as yielding values proportional to the energy of the magnetic disturbance.

As to our u-measure, it was possible[7] to estimate roughly a lower limit for the total purely magnetic energy involved in the post-perturbation under very simplified assumptions[14]. The average magnetic u implies a supply of energy at the rate of $0.6\times10^{17}u$ ergs per second. The rather high value of $u=2.5$ corresponds therefore to twenty million horse-power. The direct solar radiation received by the Earth on the whole daylight hemisphere is about 2×10^{24} ergs per second, that is, 10^7 times the rate of supply of purely magnetic energy, even in highly disturbed months. "While the expenditure of energy during a magnetic storm is very great, it is quite insignificant compared with the supply continually being received by the Earth through the ordinary solar radiation" (S. Chapman[14]).

6—*The u_1-measure*

While the relations between sunspot-numbers R and magnetic activity u will be discussed later (§ 12), some remarks on the frequency

[14] Mon. Not. R. Astr. Soc., **79**, 70-83 (1919). The theoretical conception of a magnetic storm has since been greatly modified—see S. Chapman and V. C. A. Ferraro, Terr. Mag., **36**, 77-97, 171-186 (1931).

[15] Union Geod. Geophys. Internat., Section Mag. Electr. Terr., Bull. No. 8, 205 ff. (1931); also previous report in Bull. No. 7, 57 ff. (1929). See also G. van Dijk, Meded. en Verh., Utrecht, No. 27 (1922), L. A. Bauer, Terr. Mag., **27**, 31-34 (1922); Ad. Schmidt, Ergebnisse der erdmagnetischen Beobachtungen in Potsdam und Seddin im Jahre 1915, 29-36, Berlin, Veröff. Met. Inst., No. 293 (1917); C. R. Duvall, Terr. Mag., **36**, 311-314 (1931).

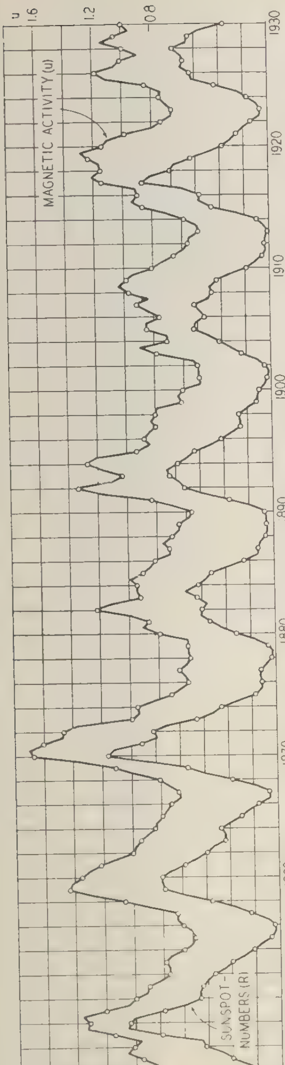


FIG. 2—Annual means of magnetic activity and relative sunspot-numbers, 1835-1930 (The points marked by small circles are the usual yearly means for January to December)

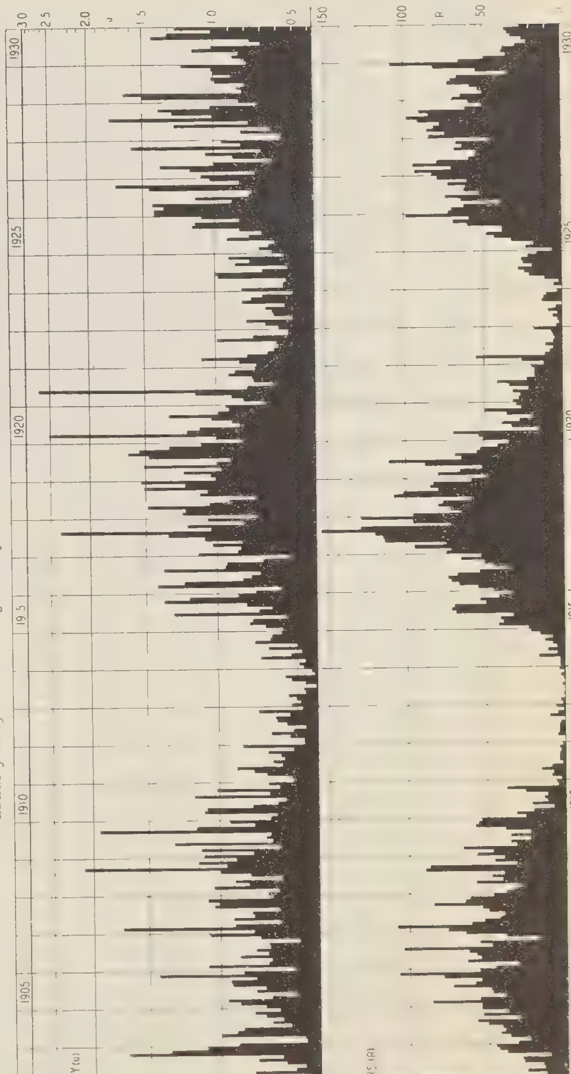


FIG. 3—Monthly means of magnetic activity and of sunspot-numbers, 1900-30

of low and high monthly means are quite necessary here. The existence of a fairly definite lower limit is a feature common to both R and u; this limit is 0 for R, and about 0.4 for u. Values in the neighborhood of these lower limits are quite frequent; judging from the 708 monthly means of the years 1872-1930, 10 per cent of all months have values of R between 0 and 3, and as many have values of u equal to or less than 0.52.

No such comparatively sharp limits exist for the high values of R and u. But while the frequency-distribution of the monthly means of R is, at the upper limit, more or less similar to the familiar exponential decrease of frequency, which is typical for frequency-curves of the types called after Gauss or Poisson[16], the distribution of u is characterized by the occasional occurrence of isolated extremely high values. This is, of course, a natural consequence of the well-known fact that some few magnetic storms are of quite outstanding intensity as compared with the rest. The three highest monthly values of u, since 1900, are due to the violent storms of August 1917 [$u = 2.37$, coinciding with the highest monthly mean (154) of R since 1872], March 1920 ($u = 2.54$), and May 1921 ($u = 2.70$).

Every measure of magnetic activity that is defined as an average of ranges, or of squares of ranges, or in a similar way, will show the same feature as u, that is, some extremely high monthly means. The monthly means of the international character-figures, however, have a different frequency-distribution, because the highest daily figures, $C = 1.9$ or 2.0, are attributed without further discrimination to all days with great storms that exceed a certain range. Take, for instance, March 1920 (with $u = 2.54$), and consider the influence of the storm on March 22 and 23 on the average interdiurnal variability U of the north component X at Seddin. The average U for the 27 differences from February 29 to March 21, and from March 25 to March 31, is 7.8γ; the average U for the whole month, by including the four big differences March 21 to March 25, is raised to 13.6γ. For comparison, the average international character-figure for the 27 days March 1 to 21 and March 26 to 31 is $C = 0.65$, and for the whole month, only slightly higher, $C = 0.79$. The few storm-days therefore nearly double the value of U (and consequently of u), but raise the average C only slightly. In other words, in the monthly means of u the great storms get more weight than in the monthly means of C or, as W. van Bemmelen[8] put it, *u is a sharper criterion for activity than is C.*

For certain purposes, it appears desirable to obtain a measure of magnetic activity which is just as well defined as u, but shares with C the property to throttle somewhat the influence of the exceptionally great disturbances. Since these great storms, as will be discussed later (§ 17), do not follow some of the periodicities exhibited by the lesser storms, the investigation of these periodicities would be hampered by the use of a measure that emphasizes them. The most general expression would call for the introduction of a suitable weight-function ρ of the difference δ from day to day, with ρ decreasing when δ is increasing ($\partial\rho/\partial\delta < 0$), and the formation of monthly average such as $\Sigma\rho\delta/\Sigma\rho$. The computing labor for such a reduction, however, would be pro-

[16] R. von Mises, Vorlesungen aus dem Gebiete der angewandten Mathematik **1**, Wahrscheinlichkeitsrechnung und ihre Anwendung in der Statistik und theoretischen Physik (Leipzig 1931).

TABLE 4—*Monthly means, u_1-measure, 1872-1930*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean	Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
...	...	...	...	...	...	...	...	...	...	...	...	...	...	1901	16	15	34	11	14	26	24	20	14	14	16	24	19
1872	72	111	92	81	75	77	106	119	93	112	86	67	91	1902	12	22	15	31	18	16	21	26	12	26	30	10	20
1873	91	56	95	82	48	62	47	57	46	46	68	48	62	1903	14	27	14	48	23	20	29	46	31	103	88	72	43
1874	64	85	79	84	41	42	51	49	51	90	49	32	60	1904	56	16	17	65	57	54	26	38	31	42	48	33	40
1875	36	72	54	46	42	35	35	25	54	39	40	19	41	1905	42	56	62	38	22	47	42	60	61	47	92	54	52
1876	27	54	47	23	19	29	24	21	31	26	31	27	30	1906	23	71	40	38	56	40	47	39	40	20	44	70	44
1877	37	31	32	21	54	42	28	37	29	42	51	27	36	1907	48	105	58	32	59	48	49	33	68	66	71	37	56
1878	40	16	13	24	20	48	18	26	38	29	26	42	28	1908	40	33	68	51	58	31	50	65	118	62	75	57	59
1879	13	19	32	25	34	53	20	23	43	30	22	40	30	1909	72	48	74	32	86	37	41	38	113	77	47	61	60
1880	22	10	37	43	33	32	42	90	63	51	73	56	46	1910	38	34	72	71	48	33	28	77	38	67	32	39	48
1881	55	75	47	44	32	40	51	41	79	55	79	47	54	1911	23	24	40	47	56	30	36	29	31	39	23	53	36
1882	42	59	45	119	52	57	64	61	42	108	136	56	70	1912	16	16	25	37	23	15	27	33	34	25	44	17	26
1883	24	54	70	72	41	49	56	50	86	47	91	48	57	1913	24	18	21	26	15	16	8	15	24	28	9	11	18
1884	59	54	48	61	51	61	69	35	66	75	85	52	60	1914	16	19	15	42	24	17	38	20	46	37	36	30	28
1885	58	57	68	58	76	61	58	48	62	40	51	44	57	1915	29	40	49	47	27	85	43	36	51	89	79	55	52
1886	75	38	60	56	61	34	56	45	42	51	56	22	50	1916	45	29	92	80	52	48	42	89	61	61	41	24	55
1887	26	26	30	52	40	39	49	49	53	34	40	52	41	1917	74	55	53	67	52	71	87	125	68	79	51	70	71
1888	72	14	39	37	56	35	29	45	29	42	35	34	39	1918	43	81	80	95	69	59	44	73	70	96	80	98	74
1889	26	27	42	25	35	48	23	28	45	28	54	30	34	1919	66	68	80	63	97	65	58	94	102	98	86	72	79
1890	18	21	19	18	25	24	17	18	37	56	48	14	26	1920	52	65	129	79	73	53	57	67	86	64	59	61	70
1891	32	46	50	54	56	27	59	57	75	42	52	59	51	1921	39	51	57	75	132	49	34	45	46	59	56	44	57
1892	64	104	102	75	104	90	100	103	54	51	77	82	84	1922	43	53	72	49	37	33	30	31	64	45	24	24	42
1893	57	78	65	57	42	72	49	100	70	72	70	56	66	1923	30	38	49	21	33	34	38	26	51	46	40	21	36
1894	51	105	93	91	59	77	103	109	80	52	90	46	80	1924	51	27	27	25	64	65	40	24	55	47	58	26	42
1895	56	92	62	58	32	53	55	47	64	75	65	45	59	1925	34	42	36	32	59	47	40	52	75	74	52	71	51
1896	50	52	70	45	82	46	46	63	61	46	49	52	55	1926	91	91	88	92	56	74	47	45	93	105	52	67	75
1897	72	48	44	68	46	39	44	31	36	39	33	75	48	1927	71	52	76	89	65	33	56	69	40	100	51	61	64
1898	24	39	78	41	39	37	27	39	98	44	52	42	47	1928	28	28	51	34	83	47	107	66	84	90	67	42	61
1899	33	63	40	30	54	28	23	34	26	16	14	20	32	1929	52	96	102	51	53	49	64	66	56	65	66	80	67
1900	40	33	79	22	70	12	13	23	18	26	10	12	30	1930	48	51	56	52	75	66	40	46	92	86	66	82	63

hibitive. Therefore, the monthly means of the modified measure, u_1, was simply defined as a function of the monthly mean of u; the function was chosen so that the monthly means of u_1 had a frequency-distribution similar to that of the sunspot-numbers R, at least for the high values. After some trials, the combination of linear and quadratic functions indicated in (5) was found suitable.

$$
(5)\quad \begin{cases} \text{For } u \leq 0.6, & u_1 = 100u - 30 \\ 0.6 \leq u \leq 1.6, & u_1 = 30 + 100\,(u-0.6) - 30\,(u-0.6)^2 \\ 1.6 \leq u \leq 3.6, & u_1 = 100 + 40\,(u-1.6) - 10\,(u-1.6)^2 \\ u \geq 3.6, & u_1 = 140 \end{cases}
$$

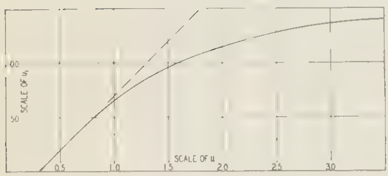


FIG. 4—The u_1-measure of magnetic activity as derived from the monthly means of u

u_1 as a function of u is represented in Figure 4. The monthly and annual means of u_1 are given in Tables 4 and 5. It may be mentioned that the variable scale chosen for u in the diagram of the monthly means (Fig. 3) is equivalent to the introduction of u_1, and has served to make that diagram clearer. The advantage of u_1 over u will also appear in §§ 10 and 16.

TABLE 5—*Annual means, u_1-measure, 1872-1930*

Mean	u_1	Mean	u_1	Mean	u_1	Mean	u_1	Mean	u_1	Mean	u_1
....	....	1881.0	56	1891.0	38	1901.0	18	1911.0	42	1921.0	66
...	....	1881.5	54	1891.5	51	1901.5	19	1911.5	36	1921.5	57
....	....	1882.0	60	1892.0	74	1902.0	19	1912.0	29	1922.0	48
1872.5	91	1882.5	70	1892.5	84	1902.5	20	1912.5	26	1922.5	42
1873.0	85	1883.0	65	1893.0	70	1903.0	23	1913.0	25	1923.0	35
1873.5	62	1883.5	57	1893.5	66	1903.5	43	1913.5	18	1923.5	36
1874.0	59	1884.0	59	1894.0	74	1904.0	53	1914.0	19	1924.0	40
1874.5	60	1884.5	60	1894.5	80	1904.5	40	1914.5	28	1924.5	42
1875.0	51	1885.0	63	1895.0	69	1905.0	40	1915.0	40	1925.0	42
1875.5	41	1885.5	57	1895.5	59	1905.5	52	1915.5	52	1925.5	51
1876.0	34	1886.0	52	1896.0	58	1906.0	52	1916.0	58	1926.0	71
1876.5	30	1886.5	50	1896.5	55	1906.5	44	1916.5	55	1926.5	75
1877.0	31	1887.0	40	1897.0	53	1907.0	51	1917.0	58	1927.0	66
1877.5	36	1887.5	41	1897.5	48	1907.5	56	1917.5	71	1927.5	64
1878.0	31	1888.0	44	1898.0	43	1908.0	50	1918.0	76	1928.0	54
1878.5	28	1888.5	39	1898.5	47	1908.5	59	1918.5	74	1928.5	61
1879.0	30	1889.0	35	1899.0	46	1909.0	65	1919.0	75	1929.0	72
1879.5	30	1889.5	34	1899.5	32	1909.5	60	1919.5	79	1929.5	67
1880.0	30	1890.0	28	1900.0	32	1910.0	56	1920.0	80	1930.0	62
1880.5	46	1890.5	26	1900.5	30	1910.5	48	1920.5	70	1930.5	63

NOTE—The value entered for 1872.5 is the mean for the 12 months January to December 1872, that for 1873.0 is the mean for the 12 months July 1872 to June 1873, etc.

7—The annual variation of magnetic activity

The 59 years, 1872-1930, were classified into three groups of high, medium, and low activity, which comprised 20, 19, and 20 years, respectively, and were selected according to the annual means of u_1 ($u_1 \geqq 58$, $57 \geqq u_1 \geqq 43$, and $42 \geqq u_1$). The average monthly means of u_1 in each group and for all 59 years are shown in Table 6; in preparing Figure 5, the monthly means were slightly smoothed, according to the formula $b' = (a+2b+c)/4$, where a, b, and c are three consecutive monthly means in Table 6. The well-known maxima near the two equinoxes (March and September) and the minima near the solstices (June and December) are clearly shown in all curves.

The standard deviations, σ_m, of the monthly means in each of the 4 lines of Table 6 (formed in the usual way using the departures of the monthly means from the respective annual means and computing the square root of the average square of the departures) are:

High, 6.6; medium, 5.8; low, 3.2; all, 4.7

On the other hand, if we form *for each single year* the departures of the 12 monthly means from their respective mean of the year, we get as standard deviation σ of these departures

High, 19.5; medium, 17.9; low, 12.0; all, 16.7

If we consider σ to be caused by two more or less independent influences, a regular annual variation (with standard deviation σ_m), and variations of other kinds (with standard deviation σ'), we may assume the relation

$$\sigma^2 = \sigma_m^2 + \sigma'^2 \qquad (6)$$

Since σ and σ_m are known, we get for σ'

High, 18.3; medium, 16.9; low, 11.5; all, 16.0

TABLE 6—*Average monthly means u_1-measure of activity, 1872-1930*

Years of activity	Number of years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
High.....	20	59.6	70.6	76.9	70.6	63.6	58.8	64.8	71.7	74.4	80.2	71.3	61.8	68.7
Medium..	19	40.8	47.4	54.3	50.9	53.1	44.6	43.8	50.8	59.4	55.2	60.5	49.4	50.8
Low ..	20	28.1	30.4	35.6	31.8	34.6	30.0	26.5	28.8	35.5	36.6	34.0	29.0	31.7
All......	59	42.9	49.5	55.6	51.1	50.4	44.5	45.1	50.4	56.4	57.3	55.2	46.6	50.4

The ratio σ_m/σ' is

High, 0.36; medium, 0.34; low, 0.28; all, 0.29

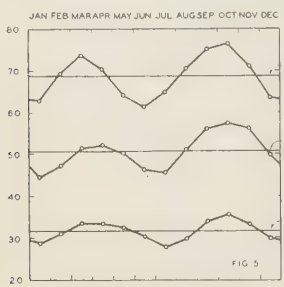
The regular annual variation is therefore not only absolutely more pronounced in years with high activity, but also relatively as compared with the fluctuations of the single monthly means. In a rough average, the magnitude of the annual variations, expressed by σ_m, is about one-third that of the non-seasonal fluctuations, expressed by σ'.

If it were thought necessary to prove the physical reality of the annual variation even more definitely, one could use the standard deviations in the following way: Suppose that σ does not contain a

systematic part such as the annual variation. According to the law of propagation of accidental errors, we should then expect that the average monthly means, taken for a number of years N, should have the standard deviation $\sigma/\sqrt{N}$; the ratio σ_m: $(\sigma/\sqrt{N})$ could therefore be regarded as an index for the reality of the annual variations. This ratio, easily calculated from the values given above [for instance, for high activity, 6.6: $(19.5/\sqrt{20})$], is

High, 1.5; medium, 1.4; low, 1.2; all, 2.2

That this ratio is always greater than unity, especially in the mean of all years, indicates the reality of the annual variation[17].



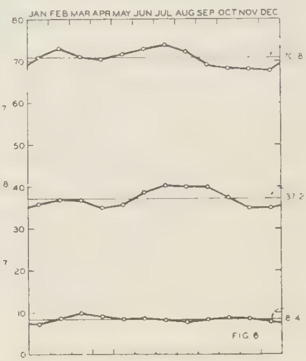


FIG. 5—Annual variation of the magnetic activity u in years of high, medium, and low activity

FIG. 6—Annual variation of sunspot-numbers in years with many, average, and few sunspots

8—*The annual variation of sunspot-numbers* ("*Earth-effect?*")

It has been suggested[18] that an "Earth-effect" can be traced in the sunspots, in the form of a small, but significant, annual variation of the sunspot-numbers R. This can be tested in the way just indicated for annual variation of the magnetic activity. From the 59 years 1872-1930, three groups of years with many, average, and few sunspots were selected according to annual means of R ($R \geqq 54$, $54 > R \geqq 20$, and $20 > R$). The average monthly means of R in each group are given in Table 7, and smoothed graphs according to $b' = (a+2b+c)/4$ are given in Figure 6. In the order of many, average, few, all sunspots, the standard deviations, defined as above, are σ_m: 3.18, 2.34, 1.08, and 1.55; and σ: 16.4, 14.7, 6.1, and 13.1. The crucial ratios, σ_m: $(\sigma/\sqrt{N})$, are: 0.9, 0.7, 0.8, and

[17] This test for reality of an average variation, which does not refer to sine-waves, was first applied by the author in Ann. Hydrogr., **51**, 153-160 (1923), and amplified in Q. J. R. Met. Soc., **51**, 173-176 (1926). It resembles the periodogram-analysis in the form given by E. T. Whittaker and G. Robinson in The calculus of observations, 345 ff., London (1924).

[18] L. A. Bauer, Terr. Mag., **26**, 114 (1921); L. A. Bauer and C. R. Duvall, Terr. Mag., **30**, 200-201 (1925); H. H. Clayton, World weather records, Smithsonian Misc. Collect., **79**, page V (1927). The series for the solar constant of radiation since 1919, published by C. G. Abbot, Smithsonian Misc. Collect., **85**, No. 1 (1931), has been discussed, as to an annual period, by Fr. Baur, Met. Zs., **49**, 15-18 (1932). The low correlation-coefficients between monthly means of the solar constant and sunspot-numbers, as compared with the high correlations between sunspot-numbers and magentic activity (§§ 12, 15), did not encourage a discussion of relations between the solar constant and magnetic activity.

0.9. Since these ratios are all smaller than unity, no physically real annual period is indicated, so that the curves in Figure 6 are all accidental in nature.

In selecting groups of years with many or few sunspots and calculating the annual variation for these groups separately, the possibility of a systematic spurious "curvature-effect"[19] must be considered. In the case of many sunspots, for instance, this selection is equivalent to the superposition of 12 monthly intervals cut out from the crests of the 11-year cycles. On the crests, however, the curves have a predominant convex curvature (negative second derivative); this systematic curvature is not eliminated or smoothed by the superposition. The order of magnitude of this effect can be judged as follows: Idealize the 11-year cycle of R as consisting of perfect sine-waves, each with a total amplitude of 100. If 3 intervals, of 12 months each, are cut from every crest, the average annual variation would show a value of R for the month in the middle of the 12-monthly interval that would be 1.8 units higher than the average of the two months at the ends of the interval. Intervals cut from January 1 to December 31 would therefore show higher values of R for June and July than for January and December; but this could never be interpreted as an "Earth-effect," for the simple reason that

TABLE 7—*Average monthly means sunspot-numbers, 1872-1930*

Number of Sunspots	Number of Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
Many....	20	69.6	77.6	67.4	71.9	70.9	73.0	74.7	73.4	67.8	67.8	69.3	66.0	70.8
Average..	19	34.6	37.6	38.0	33.6	35.2	38.7	42.2	38.1	42.0	37.7	32.7	36.3	37.2
Few.....	20	7.2	7.8	11.4	8.4	8.3	8.8	8.6	7.0	8.7	8.9	8.7	7.6	8.4
All......	59	37.2	41.0	39.0	38.0	38.2	40.2	41.8	39.6	39.4	38.1	37.0	36.6	38.8

intervals cut from July 1 to June 30 would show the spurious effect in the other direction, that is, comparatively high values in January and December, low values in June and July. Years of minimum sunspots would show concave curves for the annual variation.

The nature of this curvature-effect implies that it is not eliminated by the use of long series of observations, but, on the contrary, is even more pronounced in relation to accidental variations. From the 100 years, 1826 to 1925, two sets of years (months January to December) were selected, namely, 5 around each of the sunspot-maxima, and 5 around the sunspot-minima. Half-yearly means were derived, for northern summer (April to September) and northern winter (January to March, October to December). The resulting average sunspot-numbers during 1826 to 1925 are as shown:

Years	Northern summer	Northern winter	Summer minus winter
45 maximum	77	73	+4
45 minimum	17	19	−2
All 100, 1826-1925	46	46	0

[19] J. Bartels, Wien-Harms, Handbuch der Experimentalphysik, **25**, I, 166 (1928); see also Beitr. Physik. frei. Atmos., **11**, 51-60 (1923).

Since the "summer" half-year forms the central part of the selected intervals of years, the last column shows the marked curvature-effect.

Fortunately, however, the curvature-effect is in the interval 1872 to 1930, with which we deal, so small as compared with the accidental variations, both for R and u_1, that the values in Tables 6 and 7 are not noticeably affected by it. It was even not found necessary to apply in these tables any corrections for non-cyclic changes, that is, for progressive quasi-linear changes throughout the year.

Harmonic analysis of the annual variation of R will be discussed later (§ 10) and will confirm the results already obtained.

9—*Tests for explanations of the equinoctial maxima of activity*

The Sun passes the celestial equator on about March 21 and September 23, the time of the equinoxes. The Sun's axis of rotation is inclined 7°.2 to the ecliptic; the greatest inclination of the north pole of the Sun, that is, the time when we see most of the northern hemisphere of the Sun, occurs about September 7, while about March 5 the Sun shows us most of its southern hemisphere. Otherwise expressed, the radius from the Sun's center towards the Earth attains 7°.2 northern heliographic latitude about September 7, and 7°.2 southern heliographic latitude about March 5. For convenience, let us refer by the symbols Eq and Ax to the times of the astrononomical phenomena, just mentioned; they follow each other within only 16 days.

Arguments have been brought forward which assign the cause for the equinoctial maxima of activity to either of Ax or Eq, that is, to particular values of either the Earth's heliocentric coordinates or the Sun's geocentric coordinates. The first explanation is[20] based on the fact that sunspots occur most frequently in heliographic latitudes 10°-15°, while the equatorial belt of the Sun shows comparatively few spots. If, then, the corpuscular solar streams start from the same belts in which the sunspots occur, and leave the Sun's surface in a radial direction, they should be more likely to sweep across the Earth in September, if they are emitted from the northern spotted belts, and in March, if they are emitted from the southern belt. S. Chapman[21] simplifies the question in the following way: Suppose the streams to be shaped like spherical cones, with the apex in the Sun and with angular breadths α (angle formed by an axial cross-section); the axes of the cones may be inclined 12°.5 north and south of the Sun's equator. Near the equinoxes, then, of all streams with $11° \leq \alpha \leq 40°$, only those from one zone will sweep across the Earth, while near the solstices streams of both zones will traverse the Earth, but only if $\alpha \geq 25°$. The Ax-explanation of the two maxima in the annual variation of activity would therefore imply that narrow streams with $\alpha \leq 11°$ are more than twice as numerous as those with $\alpha \geq 25°$.

The last statement can at once be tested in the following way: A stream of angular breadth α does not take more than $\alpha \times (27/360) = 0.075\alpha$ days for traversing the Earth. The values 11° and 25° for α would therefore correspond to 0.8 and 1.9 days, respectively, and the Ax-explanation would imply that disturbed periods of duration 0.8 day

[20] A. L. Cortie, Mon. Not. R. Astr. Soc., **73**, 52-60 (1913) and **76**, 15-18 (1916); L. Rodés, Terr. Mag., **32**, 127-131 (1927).

[21] S. Chapman, Mon. Not. R. Astr. Soc., **89**, 465 (1929).

were more than twice as numerous as those of two-days' duration. This inference is not at all supported by the character-figures, which only seldom show isolated disturbed days, but, as a rule, two or more disturbed days in succession (see Fig. 18). However, two hypotheses offer themselves for saving the Ax-explanation: First, it is quite likely that the streams are not spherically symmetrical, but have elliptical form, with the longer diameter parallel to the Sun's equator; or, what is equivalent, the disturbed regions on the Sun are more extended along the Sun's circles of latitude than along the Sun's meridians (This would hold for sunspots, which "invariably stream out in longitude," but not for faculae, which "frequently appear in streaks roughly at right-angles to the direction of the Sun's rotation", see § 18); and, second, the magnetic disturbance may last for some time after the corpuscular stream has traversed the Earth.

More fundamental are three other, independent, tests of the Ax-explanation.

The two hemispheres of the Sun vary, to a certain degree, independently in the 11-year cycle. For instance, for years in succession the southern hemisphere may show more sunspots than the northern hemisphere (thus in the years 1883-89, 1895-1900, 1907-12). In such years the Ax-explanation would lead us to expect higher magnetic activity in February, March, and April than in August, September, and October. An attempt to apply this test meets the formal difficulty that the average sunspot-areas, separated for northern and southern hemispheres, are published only for intervals corresponding to solar rotations, and not to months, for which u_1 is available. Fortunately, E. W. Maunder[22] has published a suitable table for the mean daily areas of faculae, corrected for foreshortening and expressed in millionths of the Sun's visible disc, for each month from 1886-1915. This table was used in the following way: First only the months February, March, April, and August, September, October were considered, in which the Sun's axis is most inclined towards the Earth and of these months only those in which the total area was more than 300, and in which the area of faculae on the northern (or southern) hemisphere exceeded the area on the other hemisphere at least in the ratio 3:2. Then two groups were formed for: (1) the "favorable" group for which all those single months February, March, and April were selected in which the southern hemisphere had more faculae than the northern, and all those single months August, September, and October in which the northern hemisphere had more faculae than the southern; (2) the "unfavorable" group containing those in which the other hemisphere was preferred. Means of the areas and of the magnetic activity u_1 were formed as shown in Table 8.

The total area of faculae is practically the same for both groups, and so is the magnetic activity u_1, in spite of the fact that the solar hemisphere turned towards the Earth contains for the "favorable" grouping more than double and for the "unfavorable" grouping only half as many faculae as the other hemisphere. This is certainly a serious argument against the Ax-explanation. For, although the active areas (the M-regions, see § 18) on the Sun's surface, which are responsible for terrestrial-magnetic activity, cannot always be identified with sunspots or faculae, it is fairly safe to assume that the M-regions will, on the

[22] Mon. Not. R. Astr. Soc., **80**, 724-738 (1920).

TABLE 8—*Comparison of areas of faculae in millionths of Sun's disc and of magnetic activity, u_1, for favorable and unfavorable groupings*

Item	"Favorable" grouping	"Unfavorable" grouping
Number of months in group	29	33
Mean areas of faculae on nothern or southern hemisphere:		
On solar hemisphere turned towards the Earth	835	380
On solar hemisphere turned away from the Earth	345	778
On whole disc	1180	1158
Mean magnetic activity u_1	50.2	52.3

average, also be more frequent on that hemisphere where faculae are abundant.

10—*Tests using harmonic dial and probable-error circle*

The second test consists in the following determination of the exact time of occurrence of the two maxima in the annual variation. The 12 monthly means of u_1 for each single year, 1872-1930, were submitted to harmonic analysis[23], in the usual form

$$(7)\quad a_1 \cos t+b_1 \sin t+a_2 \cos 2t+b_2 \sin 2t=c_1 \sin (t+\alpha_1)+c_2 \sin (2t+\alpha_2)$$

where t is the time, increasing from the beginning of January to the end of December from 0° to 360°. The harmonic coefficients were corrected for non-cyclic change and for the effect of smoothing (because of the use of monthly means). The harmonic analysis of the mean values for the three groups of years (as given in Table 6) is given in Table 9. (The monthly means were regarded as representing equidistant values centered at the middle of each monthly interval used for calculating u, so that $t=15°$ for the day January 16.0, etc. Some calculations showed that the dates given for the maxima would not be affected by more than about one day, if the different lengths of the months were taken into account.)

To estimate the reliability of the harmonic analyses, the harmonic constants for each single year were subjected to the period-test as introduced by the author[24]. It will be explained for the case of the second harmonic (6-monthly period). The coefficients a_2 and b_2 for each year are used as rectangular coordinates (a_2 positive upward, b_2 positive towards the right) in a "*harmonic dial*" (Fig. 7), so that each year is represented by a point; the distance of this point from the origin is equal to the amplitude c_2 on a certain scale, and the direction of the vector drawn from the origin to the point gives the phase, indicated on the dial by the times (two in a year) when the maxima occur.

The 59 points are well scattered, but the maxima show a definite preference for the two sectors of equinoctial months, March and April or

[23] For the method used see J. Bartels, Beitr. Geophysik, **28**, 1-10 (1930).

[24] Berlin, Veröff. Met. Inst., Nr. 346 (1927); Zs. Geophysik, **3**, 389-397 (1927). An exposition of these methods, in their relation to others, is in preparation.

TABLE 9—*Results harmonic analysis magnetic activity u_1, 1872-1930*

Years of activity	12-monthly part		6-monthly part		Maximum 12-monthly part occurs	Maxima 6-monthly parts occur
	Ampli. c_1	Phase α_1	Ampli. c_2	Phase α_2		
High.........	2.74	160.1	8.79	281.0	Oct. 21	Mar. 26, Sep. 24
Medium......	3.24	166.8	6.85	245.4	Oct. 14	Apr. 13, Oct. 12
Low.........	0.58	133.0	4.30	245.4	Nov. 17	Apr. 13, Oct. 12
All..........	2.15	160.9	6.34	261.0	Oct. 20	Apr. 5, Oct. 4

September and October. The center of gravity of all points corresponds to the harmonic coefficients of the 6-monthly wave as computed from all years. The distances $d_1, d_2, \ldots\ldots d_{59}$ of all single points from this center

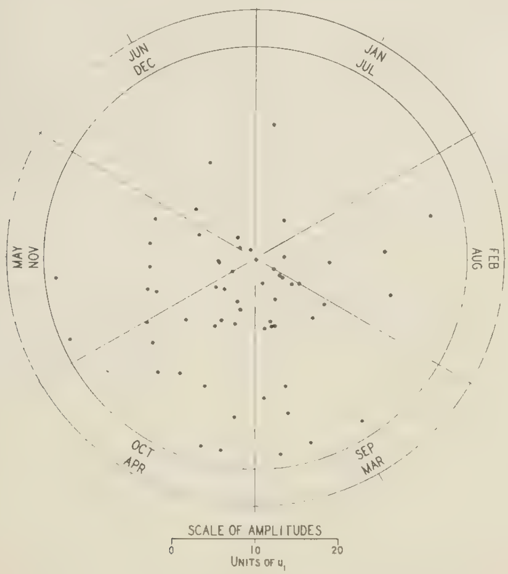


FIG. 7—Harmonic dial for the 6-monthly waves in the magnetic activity u_1 for each of 59 years, 1872 to 1930

of gravity were determined. The *standard deviation* M_2 for the second harmonic of each single year from that for the mean for all years is determined by

$$M_2^2 = (d_1^2 + d_2^2 + \ldots\ldots + d_{59}^2)/59 \tag{8}$$

The standard deviation m_2 for the mean second harmonic of 59 years is then

(9) $$m_2 = M_2/\sqrt{59}$$

and the *probable error* for the mean is

(10) $$p_2 = 0.833\ m_2$$

(Equation (10) gives, if the distribution is normal, p_2 in the usual meaning that as many deviations are greater as are smaller than p_2. If the normality of the distribution is not tested, it is understood that p_2 means nothing but a constant multiple of the standard deviation m_2.) Standard deviations were also computed for each of the three groups, by comparison of the harmonic constants for the single years with those for the respective group-means. The same calculations were made for the first harmonic, that is, the 12-monthly sine-wave, as given by the coefficients a_1, b_1.

The advantage of the method used here, as compared with the periodogram-method in its usual form, is the comparison of the average amplitude of a period with a standard deviation *which is gained by analyses restricted to periods of the same lengths.* It will be readily recog-

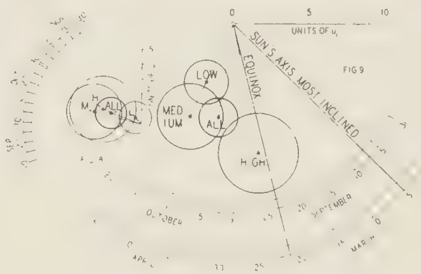


Fig. 8—Harmonic dial for the 12-monthly waves of magnetic activity u_1 in the average for groups of years with high (H), medium (M), and low (L) activity, and for all years 1872-1930—circles have radii equal to the respective probable errors p_1

Fig. 9—Harmonic dial for the 6-monthly waves in magnetic activity u_1, drawn for the groups of Figure 8—probable-error circles with p_2 as radii

nized that the method of the probable-error circle is nothing but a development of the method used in § 7, as specialized for pure sine-waves.

Table 10 contains the standard deviations and probable errors. The last two columns give the values of the ratios c_1/p_1 and c_2/p_2, that is, of the average amplitudes (as given in Table 9) to their respective probable errors.

Harmonic dials for the average 12-monthly and 6-monthly waves and their probable errors have been drawn in Figures 8 and 9. The meaning of the probable-error circle may be explained for the mean 6-monthly wave for all years: The center of the circle is the average 6-monthly wave for the 59 years 1872-1930. Suppose the series of observations could be extended as to include, say, N intervals, of 59 years each and suppose further all these intervals would show the same general statistical aspect for u_1 as the interval 1872-1930. The average 6-monthly waves, as computed from each of these N intervals, would not be the same as that computed from the interval 1872-1930; the points marking each wave, would therefore not coincide with the point marked "all" in Figure 9, but would be scattered on the harmonic dial. Though we do not know

where every single point for future intervals of 59 years will be located on the dial, we know the standard deviation m_2 that governs approximately the distribution of the points. The fundamental theorems of the theory of probability[25] assure that we are justified in assuming that the distribution will be normal, since every point represents a mean of 59 single years. That would imply that approximately $N/2$ points

TABLE 10—*Standard deviations for single years and probable errors for means of groups, first and second harmonics in annual variation of magnetic activity u_1, and ratios average amplitudes to probable errors, 1872-1930*

(The units for M_1, M_2, p_1, p_2 are those of u_1, see Tables 5 and 6)

Years of activity	Stan. dev'n M_1	Prob. error p_1	Stan. dev'n M_2	Prob. error p_2	Ratio c_1/p_1	Ratio c_2/p_2
High	11.9	2.22	14.2	2.64	1.2	3.2
Medium	9.9	1.90	11.4	2.18	1.7	3.1
Low	5.5	1.03	7.9	1.48	0.6	2.9
All	9.6	1.04	11.9	1.29	2.1	4.9

would be located inside, and $N/2$ points outside the probable-error circle around the final average. The relative frequency (or probability) that a point lies outside a circle with radius $\eta m_2 = (\eta/0.833)\ p_2$ is simply $e^{-\eta^2}$; for example, for the probable-error circle, $\eta = 0.833$ and $e^{-0.833^2} = 1/2$. A circle, with its center in the point marked "all" in Figure 9, and with its periphery passing through the origin, would have (according to Table 10) a value $\eta = 0.833 \times 4.9$, and $e^{-\eta^2} = e^{-0.833^2 \times 4.9^2} = (1/2)^{24}$ or about 10^{-7}. It would be therefore extremely improbable (with the odds 1:10,000,000) that a point would fall outside this circle. The corresponding calculation for the first harmonic, with $\eta = 0.833 \times 2.1$, gives only $(1/2)^{2.1^2} = (1/2)^{4.4} = 1/20$.

This consideration shows the superior physical significance of the 6-monthly wave as compared with the 12-monthly wave. The 12-monthly wave that enhances the values of u_1 in September and October over those in March, fairly conspicuous in Figure 5, seems therefore to be a more or less accidental feature for the interval 1872-1930, which is not very likely to return in the future. This is satisfactory insofar as the reduction-factors k (Table 1) showed some seasonal variation, which might have—but fortunately has not—introduced a slight spurious annual variation in u and u_1.

The Earth's surface receives at the time of the perihelion (beginning of January) about 6 per cent more radiation from the Sun than at the time of the aphelion (beginning of July). A similar 12-monthly period in magnetic activity might have been expected, but cannot be traced in the observations.

The 6-monthly wave is shown to be the significant physical characteristic of the annual variation. It has a fairly constant phase, but its amplitude in disturbed years is more than twice as great as in quiet

[25] R. von Miss, Wahrscheinlichkeitsrechnung, § 8 (1931).

years. If the origin of the time-variable t is chosen at the beginning of a sunspot-maximum year, and if it is assumed that the amplitude of the 6-monthly wave changes regularly with the 11-year cycle, this wave can be roughly expressed as

$$(11) \qquad [6.5+2.6 \cos (t/11)] \sin (2t+261°)$$

In the well-known manner, similar to that in tidal theory when the luni-solar terms K_1 and O_1 are derived from the lunar tidal potential[26], we can transform our expression so that it is a sum of three terms with constant amplitudes as in

$$(12) \quad 6.5 \sin (2t+261°)+1.3 \sin [2t+(t/11)+261°]+1.3 \sin [2t-(t/11)+261°]$$

The frequencies (per year) of the three terms are 2, 23/11, and 21/11, with periods 6.00, 5.74, and 6.29 months, respectively. Ordinary periodogram-analysis would therefore yield, besides the main 6-monthly wave, two waves of about 1/5 of its amplitude, and periods of 5.74 and 6.29 months, respectively; but this result differs only in form, not in physical content, from the statement of a 6-monthly wave of constant phase but variable amplitude, as expressed in Table 9.

The harmonic dial (Fig. 9) makes it evident that the maxima of the 6-monthly wave in activity occur nearer to the equinoxes than to those times when the Sun's axis is most inclined towards the Earth. This agreement in favor of the *Eq*-explanation of the annual variation, as against the *Ax*-explanation, can be put in a quantitative form: We consider the average 6-monthly wave for all years. Table 10 gives the parameters of the hypothetical bell-shaped frequency-distribution of points representing the average second harmonic in a set of intervals of 59 years each. From these we can calculate the probabilities that the maxima occur in one of three intervals of ten days each, centered on April 5 (the time of maximum found from the years 1872-1930), March 21 (equinoxes), and March 5 (Sun's axis most inclined), and the corresponding ten-day intervals half a year later. These probabilities calculated by integration over 10-day sectors in the harmonic dial, are 0.686, 0.096, and 0.000022, respectively. In other words, even though the maxima of the 6-monthly wave in activity u_1, as computed from the interval 1872-1930, occur about 14 days after the equinoxes, the chances are fairly high (0.096:0.686 = 1:7) that this is merely accidental, due to the shortness of the series, so that the maxima, as computed from a much longer series of years, might as well occur at the equinoxes. On the other hand, the chances in favor of the earlier dates *Ax* are very small (0.000022:0.686 = 1:31,000).

It may be mentioned that this sharp distinction between the two dates was made only possible by the introduction of the measure u_1. For the average of all years 1872-1930, the original u-measures gives, by a curious coincidence, the same time for the maxima of the 6-monthly wave as u_1, but the scattering of the values for the individual years is much higher for u than for u_1, so that the ratio $c_2 \cdot p_2$ for the average of all years is only 2.9 for u, instead of 4.9 as for u_1 (Table 10). Therefore, the original values u would have permitted no sharp estimate of the relative probabilities; even the chances in favor of the earlier *Ax*-dates would be rather

[26] Handbuch der Geophysik, herausgegeben von B. Gutenberg, **1**, 331 (1932).

high and indecisive, namely, 1:36, instead of the decisive low value 1:31,000 which was obtained by using u_1.

The series 1906-30 of the international character-figures C was also analyzed for its annual variation. The average monthly means, shown in Table 11, give the following harmonic coefficients, corresponding to equation (7)

$$0.631+0.011 \sin (t+49°)+0.065 \sin (2t+294°.6)$$

Analysis of the single years gives the standard deviations $M_1=0.062$, $M_2=0.061$, the probable errors (of the 25-yearly average harmonic amplitudes) $p_1=0.0104$, $p_2=0.0102$, and the characteristic ratios $c_1/p_1=1.1$, $c_2/p_2=6.4$. Again the 12-monthly wave is not significant, while the 6-monthly wave is very pronounced, with maxima on March 16 and September 18. The relative chances for the *Eq*-dates and *Ax*-dates

TABLE 11—*Average monthly means to show annual variation international magnetic character-figures, 1906-30*

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
0.612	0.682	0.712	0.621	0.639	0.576	0.578	0.619	0.696	0.696	0.576	0.568	0.631

TABLE 12—*Results harmonic analysis annual variation relative sunspot-numbers 1872-1930, same groups as Table 7*

Number sunspots	First harmonic					Second harmonic				
	Ampli. c_1	Phase α_1	Stan. dev'n M_1	Prob. error p_1	Ratio c_1/p_1	Ampli. c_2	Phase α_2	Stan. dev'n M_2	Prob. error p_2	Ratio c_2/p_2
		°					°			
Many......	2.16	308	14.4	2.65	0.8	2.36	48	10.6	1.98	1.2
Average....	2.37	237	11.3	2.17	1.1	2.28	2	8.3	1.59	1.4
Few.......	0.42	342	4.2	0.78	0.5	0.82	256	3.9	0.72	1.1
All........	1.27	277	10.9	1.18	1.1	1.34	10	8.3	0.90	1.5

are again in favor of the former, though the odds are only 7:1—which is not unexpected since the available series of observations for C is less than half as long as that for u_1.

The third test of the *Ax*-explanation will be given in § 14 and is likewise unfavorable to it.

Some physical considerations regarding the *Eq*-explanation have been given previously[27], in connection with the influence of the beginning of the day on u, and will not be repeated here.

For completeness, the annual variation of the relative sunspot-numbers R was tested by harmonic analysis in the same manner as described for the magnetic activity. The results collected in Table 12 confirm the conclusion that neither a 12-monthly nor a 6-monthly wave of physical significance can be detected in the series 1872-1930. The accidental variations veil also the curvature-effect (see § 8), which would be expected to produce opposite phases ($\alpha_1=270°$ and 90°) of the 12-monthly wave in the years with many and few sunspots; the curvature-effect is also not noticeable in the magnetic activity (Table 9).

11—*The question of annual recurrences (influence of comets and meteors)*

Simultaneous appearances of meteors and aurorae have been noticed in some cases more than 100 years ago, but no particular weight has been attached to them since the coincidences seemed to be explicable by pure chance. H. Fritz[28] in 1881 summarized his opinion as follows, after mentioning observations of Wrangel in 1821 to 1823:

> "Likewise, no particular weight can be attributed to the simultaneous appearance of northern lights with meteor-showers, as they occurred in the years 1833 and 1838 from November 12 to 13, since the stronger aurora (1838) coincided with the weaker meteor-shower, since, furthermore, many important meteor-showers occurred without intense aurora, and since, finally, the time about November 12 is as little marked for numerous aurorae as the time about August 11 or as other days of the year which are conspicuous for meteors or meteorites."

While most magneticians adopted the same opinion, H. B. Maris[29] has recently revived the question by asserting the discovery of three groups of annual recurrences of magnetic storms. While the first two groups fall before 1875, the third group is comparatively recent and can easily be tested. It is said to have started May 16, 1913, and to be almost unbroken since then. The observational data seem, in the present writer's opinion, to be at variance with the existence of this group, because the days May 15, 16, and 17, 1913, have very low international magnetic character-figures, namely, 0.5, 0.1, and 0.2, respectively, and therefore can hardly be claimed as starting a series of annually recurring magnetic storms. In fact, the extension of Maunder's list of magnetic storms which H. B. Maris uses in his paper[29], and also in a former joint paper with E. O. Hulburt[30], appears not quite satisfactory. For instance, the total number of magnetic storms, for the 78 years from 1848 to 1926, is given as 1,550. Some dates of "storms" given[30] for years after 1915 have, however, international character-figures C as low as 0.5 and 0.6 and should hardly be rated as disturbed; judging from L. W. Pollak's frequency-list for C, there have been 1,728 days with $C \geq 1.0$ in the interval 1906 to 1925 alone, that is, more than the whole list of storms for the 78 years contains. This indicates a shift in the rules for selecting storms, as compared with those used by Maunder, and also throws some doubt on the basis of the statistical considerations[31] with which the authors attempt to substantiate their interesting hypothesis of a correlation between magnetic and comet activity.

An independent search for annual recurrences was made with the help of the international character-figures C. In the years 1906 to 1930 values $C \geq 1.6$ have been assigned to a total of 392 days—on the average, about 16 per year. The monthly frequency-distribution is given in Table 13. In order to show the exact occurrence of each of these days, a chart (Fig. 10) was drawn to scale showing for each day of each of the 25 years (in leap years, the dates before March 1 are shifted one day toward the left) by distinctive symbols those days with $C = 1.6$, 1.7,

[27] See[7] and Wien-Harms, Handbuch der Experimentalphysik, **25**, I, 663-664 (1928).

[28] Das Polarlicht, p. 289 (1881).

[29] Phys. Rev., **37**, 1680-1681 (1931); **39**, 504-514 (1932).

[30] Phys. Rev., **33**, 1046-1060 (1929).

[31] *l. c.* p. 1057.

TABLE 13—*Number of days with international character-figures C between values 1.6 and 2.0, 1906-30*

C	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
2.0	4	2	5	2	5	2	2	6	6	8	1	5	48
1.9	5	8	9	5	4	6	1	4	5	9	2	3	61
1.8	5	5	9	3	8	1	4	4	14	14	5	0	72
1.7	3	7	15	6	8	6	3	10	13	9	7	8	95
1.6	14	6	6	5	10	2	11	8	15	17	14	8	116
Total	31	28	44	21	35	17	21	32	53	57	29	24	392

1.8, 1.9, or 2.0, respectively. The total area covered by the symbols is shown for each year at the right, and for each month at the bottom. The right-hand column exhibits the 11-year cycles, and annual variation appears at the bottom. Apart from a general but not exclusive preference for the times about the equinoxes, no vertical string of symbols can be discerned that would indicate a particular date preferred by magnetic storms year after year. This holds in particular for the date May 16, also May 11 and November 12 or adjacent days.

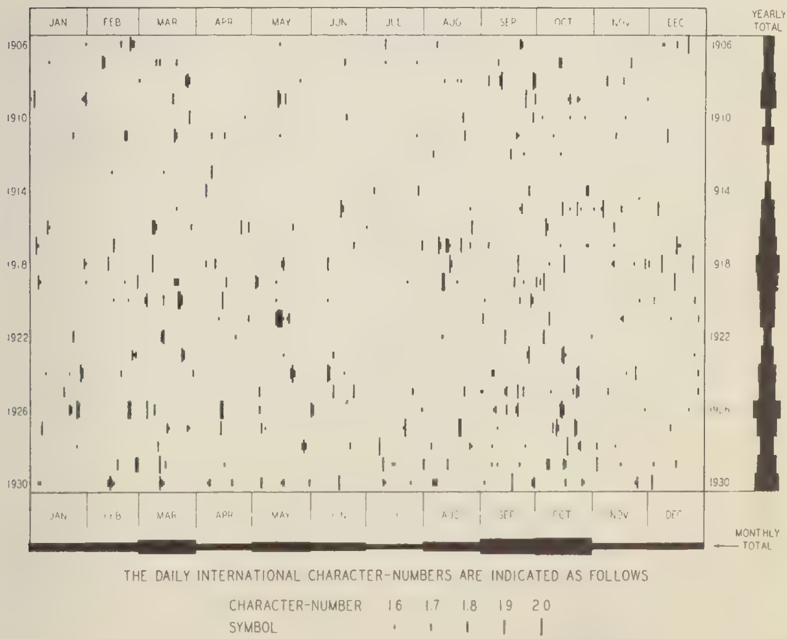


FIG. 10—Days of great magnetic disturbance, 1906-30

12—*Relations between annual means of solar activity and terrestrial-magnetic activity*

In the next paragraphs the relations between two variables x and y will be expressed in the following usual way[32]: The given values may be x_n and y_n; $n=1, 2, \ldots\ldots, N$. The standard deviations of the x_n and y_n are called σ_x and σ_y, respectively. A linear relation between x and y is established according to the methods of least squares; that is, coefficients a and b are determined, so that the computed values

$$y_n' = ax_n + b \tag{13}$$

differ from the observed values y_n as little as possible, or, more accurately, so that the sum of the squares of the *residuals*

$$\triangle y_n = y_n - y_n' \tag{14}$$

is a minimum. If x_0, y_0 are the average values of x_n, y_n, the correlation-coefficient r is defined as

$$\Sigma(x_n - x_0)(y_n - y_0)/N\sigma_x\sigma_y \tag{15}$$

and the coefficients in (13) are

$$a = r\sigma_y/\sigma_x,\ b = y_0 - ax_0 \tag{16}$$

For *normalized* variables, which are expressed in such units that $\sigma_x = \sigma_y = 1$, a is simply equal to r. In the general case, the standard deviation of y_n' is $r\sigma_y$, and that of the residuals $\triangle y_n$ is $\sigma\sqrt{1-r^2}$. In other words, y can be conceived as the sum of two parts, of which one, y', is a strictly linear function of x, and the other, $\triangle y$, is not correlated with x, or, in the suitable notation used by H. B. Heywood[33], $\triangle y$ is *orthogonal* to x. The relative magnitude of both parts y' and $\triangle y$ can be estimated from the ratio $r:\sqrt{1-r^2}$ of their respective standard deviations; this ratio remains the same when x and y change their role in (13). The reliability of r increases of course with the number N of available observations, and is expressed by its standard error, $(1-r^2)/\sqrt{N}$.

The average values of *sunspots R, magnetic activity u and u_1, during 1872-1930*, for $N=59$, are 38.9, 0.854, 50.4, respectively, and the standard deviations 27.5, 0.221, 16.9. The very high correlation-coefficients, +0.869 between R and u and +0.884 between R and u_1, indicate how close the relations are. The ratios $r:\sqrt{1-r^2}$ are 1.76 and 1.89. As could be expected, u_1 furnishes slightly better correlation with R than the original measure u; it is therefore preferred in the discussions which follow.

The average values of *sunspots R, international magnetic character-figures C, and magnetic activity u_1, 1906 to 1930* for $N=25$ are 42.3, 0.630, 53.4, respectively, and the standard deviations 27.4, 0.087, 15.9. The correlation-coefficients are +0.570 between R and C, +0.820 between R and u_1, and +0.719 between C and u_1, and the values of ratios $r:\sqrt{1-r^2}$ 0.69, 1.43, and 1.03. The inferiority of the annual mean values of the

[32] Ad. Schmidt, Met. Zs., **43**, 329-334 (1926).

[33] Proc. R. Soc., A, **134**, 486-501 (1931).

character-figures C, as compared with those of u or u_1, is revealed in these correlation-coefficients, because they give the paradoxical result that one good measure of terrestrial-magnetic activity, namely u_1, is better correlated with the sunspot-numbers R than with another, but unsatisfactory measure of terrestrial-magnetic activity, namely C (see also § 13).

We have from Greenwich the *areas of sunspots* S *and of faculae* F *during 1882-1930* for $N=49$ for comparison with *relative sunspot-numbers* R *and magnetic activity* u_1. Since 1882 the Greenwich mean areas of sunspots and faculae[34] are based on photographs taken on practically every day. The projected areas, uncorrected for foreshortening, expressed in millionths of the Sun's visible disc are used here as they are more likely to be of geophysical significance than the corrected values. Average values of S, F. R, and u_1 are 849, 1181, 39.7, and 50.9, respectively, and the standard deviations 616, 785, 26.9, and 16.7. The correlation-coefficients of u_1 are $+0.854$ with S, $+0.795$ with F, $+0.858$ with R, while the correlation-coefficient of the areas of spots S with the areas of faculae F is $+0.898$ and with the relative sunspot-numbers R is $+0.981$. *Sunspot-areas* S *are therefore not superior to the relative sunspot-numbers* R, since both give the same high correlation-coefficients with terrestrial-magnetic activity u_1, while the areas of faculae F yield a definitely *less* correlation-factor with u_1 than both S and R. The high correlation between the series S and R emphasizes the satisfactory qualities of both; with $r=0.981$, the ratio $r:\sqrt{1-r^2}$ is as high as 5.31 (see § 13).

13—*Tests of homogeneity for measures of solar and terrestrial activity*

The correlations found in § 12 are close enough to warrant tests of the following kind: The determination of the relative sunspot-numbers R as well as of areas of sunspots S and, especially, faculae F[35], is naturally uncertain and difficult enough to make special safeguards necessary in order to keep the series homogeneous. The close connection of the terrestrial-magnetic activity u_1 with the measures of solar activity makes an independent test of homogeneity possible, by actual calculations of the linear formulae (equation 13) and the residuals (equation 14). Inhomogeneity in any of the variables would be revealed by a conspicuous trend in the residuals; which one of the variables is taken as y and which one as x (equation 13) is not important, as long as it is not forgotten that the regression of y on x is not the same as that of x on y.

Starting from the annual means 1882 to 1930, the variables F, R, and u_1 were expressed as linear functions of the sunspot-areas S, namely

$$F=1.146S+208 \tag{17}$$

$$R=0.0428S+3.3 \tag{18}$$

$$u_1=0.229S+31.4 \tag{19}$$

Figure 11 shows the observed values of S, F, R, and u_1, and the residuals $\triangle F$, $\triangle R$, and $\triangle u_1$ (observed minus computed values). The ratios of

[34] Mon. Not. R. Astr. Soc., **49**, 381 (1889); **63**, 465 (1903); **76**, 402 (1916); **84**, 742 (1924); **91**, 1005 (1931).

[35] Mon. Not. R. Astr. Soc., **84**, 96-99 (1924).

the standard deviations of F, R, and u_1, to the standard deviations of the residuals $\triangle F$, $\triangle R$, and $\triangle u_1$ are $r:\sqrt{1-r^2}$, for which the correlation-coefficients in § 12 give 2.04, 5.31, and 1.64. The scales for the observed values have been approximately normalized, that is, chosen so that the amplitudes of the various curves are not too different. The scales for

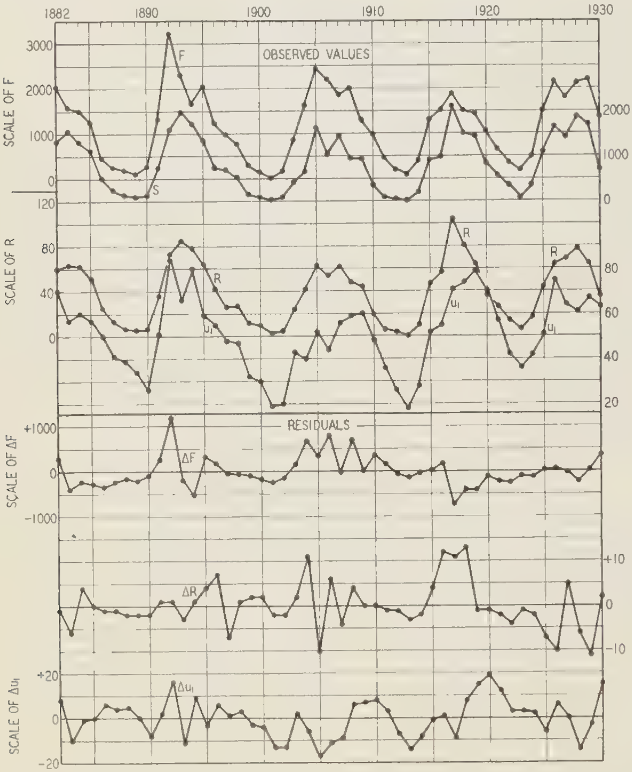


Fig. 11—Tests of homogeneity for sunspot-areas S, faculae-areas F (both projected, uncorrected for foreshortening, and in millionths of the Sun's visible disc), relative sunspot-numbers R, and terrestrial-magnetic activity u_1, 1882-1930 (Upper curves give observed values F, S, R, and u_1, while lower curves give residuals ΔF, ΔR, and Δu_1, that is, algebraic excesses of observed values over those computed from S by least-square linear-formulae)

F and $\triangle F$ are equal, also those for u_1 and $\triangle u_1$, but the scale of $\triangle R$ was magnified four times that of R in order to show the details.

$\triangle F$ does not change its sign irregularly from year to year, but shows definite persistence. The large value for 1892 is puzzling, also the long interval of positive signs from 1903 to 1911, and the negative signs from 1917 to 1924. $\triangle R$ is satisfactorily small; it is an interesting feature that for three years in succession, 1916 to 1918, the observed relative sunspot-number R has been more than 11 units higher than the simul-

taneous sunspot-areas S would have suggested. So, either R is too high or S is too low for these years; the former alternative seems likely from the comparison of R and u_1 (§ 14).

Figure 12 indicates that the larger residuals $\triangle F$ and $\triangle R$ occur, as would be expected, in the years of sunspot-maxima and that they cannot be explained by non-linear regression, that is, by systematic deviations of the general relations from straight lines. A slight improvement would be possible were the regression line drawn through the origin. Further comment on the observational or physical nature of the residuals $\triangle F$ and $\triangle R$ which we have shown in Figures 11 and 12 is a matter mainly of astrophysical interest and is therefore not discussed.

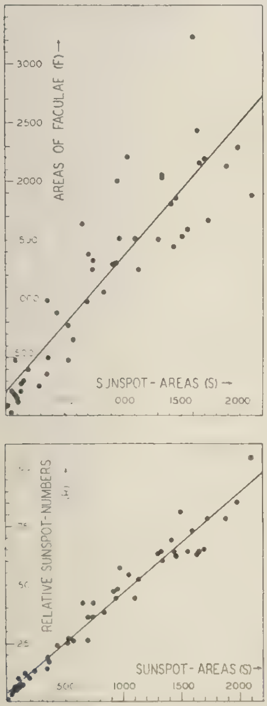


Fig. 12—Linear adjustments of relations areas of faculae F to sunspot-areas S (upper) and of sunspot-numbers R to sunspot-areas S (lower), each dot representing a pair of annual means in the 49-year series, 1882-1930

The linear relation between the 25 annual means of C and u_1 is

$$(20) \qquad C=0.00392u_1+0.421$$

The residuals $\triangle C$ between the observed values of the international magnetic character-figures C and those computed from u_1 are considerable, the standard deviations of $\triangle C$ and C being nearly equal. This is verified by Figure 13. The outstanding residual for the year 1930 indicates that C was estimated, on the average, 0.16 unit higher in that year than the value for u_1 would suggest. The suspicion of a spurious shift in the character-estimation C is confirmed by the fact that, in the whole series of 25 years, 1930 has the highest annual mean (0.83) and April 1930 the highest monthly mean (1.04), while both intervals are not at all outstanding if judged by the objective measures u or u_1 or other numerical measures of activity which are based on daily ranges (C. R. Duvall[15]). It is not unlikely that this signifies a break in the homogeneity of the series of international character-figures, which may be due to the new practice, adopted by some observatories, of determining the character of actual measurement of ranges, etc., contrary to the original conception (§ 2). The increased frequency of the higher values for C is noticeable in our Figures 10, 18, and 19, but does not vitiate the conclusions drawn from these diagrams and has, especially, no influence on the identification of the 27-day sequences in Figures 18 and 19.

14—*The lag of the annual means of terrestrial-magnetic activity behind those of solar activity*

The last curve in Figure 11 shows such definite persistence in the signs for $\triangle u_1$ for several successive years that it was thought worth

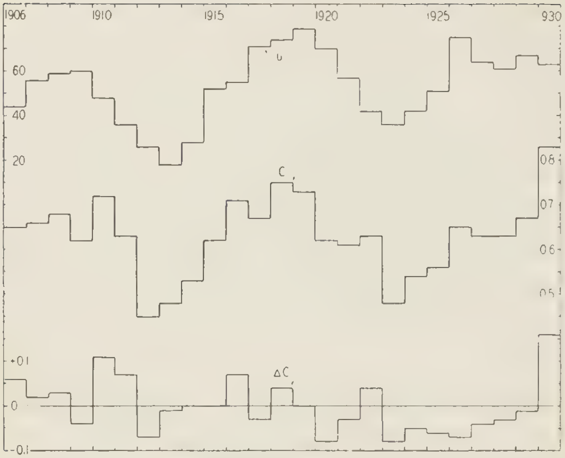


FIG. 13—Observed annual means magnetic activity u_1, international magnetic character-figures C, and residuals $\Delta C = C - C'$ between the observed values C and values $C' = 0.00392u_1 + 0.421$, computed by linear least-square adjustment

while to study this phenomenon by using all the annual means for the series 1872 to 1930 as given in Table 5. Figure 14 shows that the fit of the linear formula

(21) $$u_1 = 0.543R + 29.3$$

can be improved by taking into account the characteristic steeper ascent for the lower values; accordingly, the curved regression-line L shown in Figure 14 was chosen. From $R=0$ to $R=20$, u_1 increases, on L, by 20 units instead of only 11 units on the straight line; this characteristic feature (that the same increase in sunspot-numbers R affects the magnetic activity u_1 generally nearer sunspot-minimum than maximum) is well brought out by the distribution of the dots in Figure 14.

The sensitivity of the magnetic activity for small changes of R near sunspot-minimum is noticeable in 1923 (Fig. 2), when u_1 did not reach the low values of 1901 and 1913, because "1923 did not have the pronounced character of a sunspot-minimum year as, for example, 1901 and 1913" (A. Wolfer[36]).

The regression-line L defines u_1' as a function of R. The graph representing u_1' for the series 1872-1930 (Fig. 15) is therefore nothing but a transformation of the graph representing R in Figure 2, consisting in a deformation of scale, according to L; if the R-graph in Figure 2 were drawn on some elastic material, the u_1'-graph in Figure 15 could be obtained from it by stretching or compressing the vertical distances between consecutive horizontal lines, till the non-uniform scale of R on the right-hand side of Figure 15 would be obtained. The residuals $\Delta u_1 = u_1 - u_1'$ are plotted in the second row of Figure 15; superposition

[36] Astr. Mitt., Nr. **114**, 117 (1926).

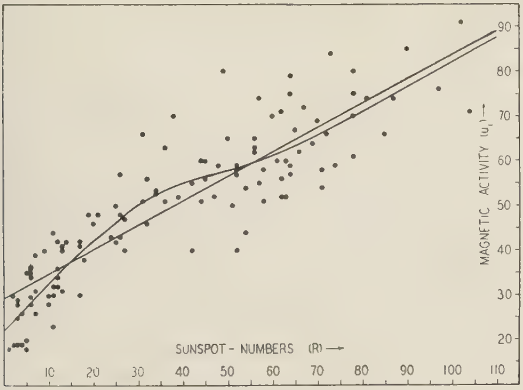


FIG. 14—Annual means of relative sunspot-numbers R and terrestrial-magnetic activity u_1, each dot marking a pair of values, for each of 117 annual means (for intervals January to December and July to June), 1872-1930; straight line by least-square adjustment and a curved regression-line L are shown

of the two graphs for u_1' and for $\triangle u_1$ would give the graph of the observed values u_1.

On the whole, no progressive trend can be detected in $\triangle u_1$. The result of our test indicates therefore *that the sunspot-numbers R as well as the measure u_1 of magnetic activity are fairly homogeneous throughout the interval 1872-1930.* As to the discrepancy between sunspot-areas S and sunspot-numbers R in the years 1916-18, mentioned above, it would seem now that it is due to high values of R, since the values u_1', as

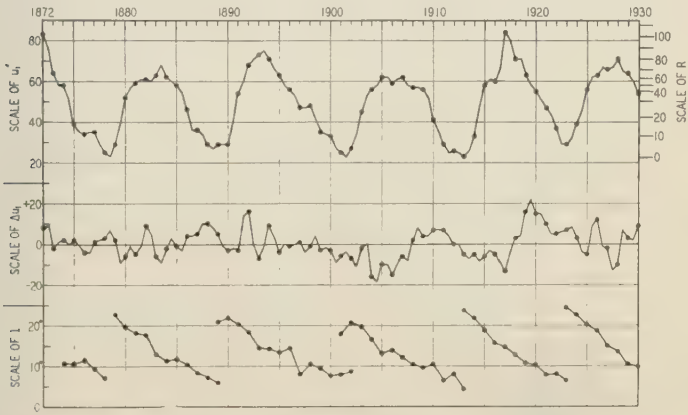


FIG. 15—Annual means of magnetic activity u_1' as computed from sunspot-figures R by regression-line L in Figure 14, residuals $\Delta u_1 = (u_1 - u_1')$ and average distance (latitude) l of sunspots from Sun's equator

computed from R, are also too high as shown by the negative $\triangle u_1$ in Figure 15.

The characteristic persistence of the sign of $\triangle u_1$ for several successive years, which was noticeable in Figure 11, reappears in Figure 15. The phenomenon is pronounced in the interval 1900-25, when negative signs of $\triangle u_1$ prevail during the ascent to a sunspot-maximum and positive signs prevail during the descent to a sunspot-minimum. This amounts to a lag of the annual values of u_1 behind R, and substantiates previous results obtained from shorter series[37]. Before 1900, the lag was only noticeable from 1886-89. The lag (when it occurs) can also be expressed in the statement that a certain value of the magnetic activity u_1 in the *descending* phase of the sunspot-cycle is connected with a relative sunspot-number R, that is about 20 units lower than that number R which would be connected with the same u_1 in the *ascending* phase. This phenomenon has been explained by the well-known fact that the sunspots of a new cycle appear in high latitudes of the Sun and gradually approach the Sun's equator. The average solar latitudes l of sunspots, that is, their average distance from the solar equator, have been plotted in Figure 15 according to the Greenwich observations for each year. Radial streams of solar corpuscles are therefore more likely to traverse the Earth's orbit in the descending phase of the cycle, when sunspot-latitudes are low.

This explanation follows qualitatively the same lines as the *Ax*-explanation for the annual variation of magnetic activity (§ 9), but a quantitative test is again unfavorable to the latter. According to Table 9 (mean for all years), u_1 is near the equinoxes $2c_2 = 12.7$ units higher than near the solstices; therefore, judging from the linear equation (21), relative sunspot-numbers R producing the same activity u_1 must be roughly $12.7/0.534 = 23$ units higher near the solstices than near the equinoxes. If this large effect were produced by the comparatively small changes in the Earth's heliographic latitude within the year, as the *Ax*-explanation asserts, then the great changes in the sunspot-latitudes occurring in the solar cycle should result in a greater and more systematic lag-effect than is actually found in Figure 15.

15—*Relations between monthly means of solar activity and terrestrial-magnetic activity*

Beyond a generally similar trend, Figure 3 shows some coincident features in the monthly means of sunspot-numbers R and activity u, for instance, in November 1905, February 1907, September 1908, August 1917, March 1920, March 1922, December 1929. Other similarities are the drop in activity during October 1906, in the midst of the sunspot-maximum; the revival of activity, September to December 1909; the fact that August 1917, the month with the highest sunspot-number, was also magnetically very active. The lag of u behind R in the 11-year cycle is also pronounced in the monthly means. Notable discrepancies are, for instance, the high magnetic activity of October to December 1903, at the beginning of a new sunspot-cycle, and the small

[37] See [7] and [20]; also L. A. Bauer, Terr. Mag., **23**, 66 (1918); H. W. Fisk, Terr. Mag., **34**, 147-150 (1929). High diurnal ranges of declination at Greenwich are also more frequent in the descending phase of the solar cycle than in the ascending phase, as can be seen from S. Chapman's frequency-curves based on 63 years of observations, Phil. Trans. R. Soc., A, **225**, 59 (1925).

value for R during May 1921, the month with the highest u of the whole series[38].

The periodicity of somewhat over 8 months, which is indicated in the monthly sunspot-numbers 1905-08, and which is characteristic for the weak sunspot-maxima[39], is not so easily recognized in magnetic activity.

Diagrams corresponding to Figure 14 and showing the relations between the monthly means of u_1 and R, were drawn for the three groups of years with high, medium, and low activity (§ 7), and for all years (Fig. 16). Months with $R=0$ are so numerous that they had to be indicated by dots to the left of the line $R=0$; these are considerably scattered

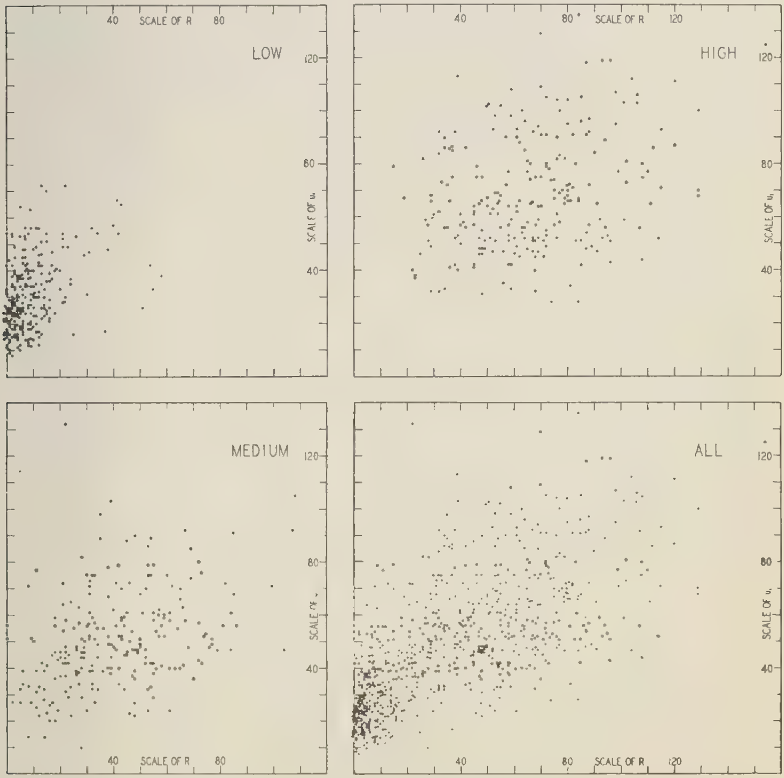


FIG. 16—Monthly means of relative sunspot-numbers R and terrestrial-magnetic activity u_1, 1872-1930: "High" for 20 years with annual means $u_1 \geq 58$; "low" for 20 years with annual means $u_1 \leq 42$; "medium" for 19 years with intermediate annual means; "all" for the 59 years—708 months

[38] Nevertheless, the great storms of May 1921 are undoubtedly of solar origin, since an extremely large naked-eye spot-group, covering 1/700 of the Sun's disc, crossed the central meridian on May 14; it was the largest group ever photographed at Greenwich on the solar equator. The relative sunspot-number R for May 14 was, however, only 63, because even the largest spot contributes only 10 units to R. This is a case where the sunspot-area S was more significant than R.

[39] A. Wolfer, Astr. Nachs., 100, 336 (1909).

in the vertical, indicating that low solar activity can be accompanied by fairly high magnetic activity. The distribution of dots in the diagrams "medium" and "high" resembles the elliptical type of "normal correlation," while in the diagram "low" the dots crowd toward the line $R=0$.

That the monthly means of u_1 and R are more loosely connected with each other than the annual means, is clearly seen from a comparison of Figures 14 and 16. The following reasons, in the supposed order of magnitude, are offered: (1) Since the relation between R and u_1 is statistical, not functional, it must appear clearer the more cases of nearly equal character are combined. This holds for the combination of monthly means into annual means (§ 16). (2) Since magnetic activity lags behind solar activity by some days, use of simultaneous intervals for R and u_1 introduces a certain boundary-effect which is, of course, relatively greater in monthly means than in annual means. (3) Because of the annual variation of u_1, the like values of u_1 are, in the equinoctial months, coordinated to simultaneous values of R that are about 20 units lower than the simultaneous values of R in the solstitial months (§ 14).

16 *General remarks on correlation in series with after-effect (monthly and annual means)*

The series of monthly means for u_1 as well as for R show definite "after-effects" insofar as means for successive months differ much less than would be expected were they independent. The statistical treatment of such series has been developed mainly for series of a single variable, in the Lexis theory, or in the theory of Brownian movement and other fluctuations[16]. The correlation between u_1 nad R offers a good example of the relations between two series of this type and the following general remarks may be useful for similar cases, for instance, in meteorological correlations.

N pairs of annual means A_n, B_n ($n=1, 2, \ldots, N$) may be given with the average values A_0, B_0. They are derived from NM monthly means a_{nm}, b_{nm} [$n=1, 2, \ldots, N$ and $m=1, 2, \ldots, M$; for monthly means $M=12$]. The departures of the monthly means from the respective annual mean are called α_{nm}, β_{nm}, thus

$$\alpha_{nm}=a_{nm}-A_n \text{ and } \beta_{nm}=b_{nm}-B_n \tag{22}$$

The standard deviations of the annual means, monthly means, and monthly departures, respectively, are called σ_A, σ_B; σ_a, σ_b; σ_α, σ_β; the correlation-coefficients are called r_{AB}, r_{ab}, $r_{\alpha\beta}$. By straightforward application of the well-known formula of the type

$$\Sigma_{n=1}^{N} A_n^2=\Sigma_{n=1}^{N} (A_n-A_0)^2+NA_0^2=N\ (\sigma_A^2+A_0^2) \tag{23}$$

$$\Sigma_{n=1}^{N} A_nB_n=\Sigma_{n=1}^{N} (A_n-A_0)\ (B_n-B_0)+NA_0B_0=N\ (\sigma_A\sigma_B r_{AB}+A_0B_0) \tag{24}$$

we obtain the symmetrical relations

$$\sigma_a^2=\sigma_A^2+\sigma_\alpha^2 \text{ and } \sigma_b^2=\sigma_B^2+\sigma_\beta^2 \tag{25}$$

$$\sigma_a\sigma_b r_{ab}=\sigma_A\sigma_B r_{AB}+\sigma_\alpha\sigma_\beta r_{\alpha\beta} \tag{26}$$

The latter formula, with

(27) $k_\alpha = \sigma_\alpha/\sigma_A$ and $k_\beta = \sigma_\beta/\sigma_B$

gives the useful relation

(28) $r_{ab} = (r_{AB} + k_\alpha k_\beta r_{\alpha\beta})/\sqrt{(1+k_\alpha^2)(1+k_\beta^2)}$

The correlation r_{ab} between the monthly means will therefore be nearly the same as that of the annual means, if the monthly departures are small in comparison to the scattering of the annual means (k_α and k_β small). The value of r_{ab} may become numerically greater than r_{AB}, if $r_{\alpha\beta}$ and k_α and k_β are great; when k_α and k_β tend to infinity, r_{ab} becomes equal to $r_{\alpha\beta}$. If, however, $r_{\alpha\beta}$ is numerically smaller than r_{AB}, r_{ab} will also be numerically smaller than r_{AB}.

Assigning the letters A and B to R and u_1, respectively, the data for the three groups of years and for all years, 1872-1930, have been collected in Table 14. Since $r_{\alpha\beta}$ is small in all cases, the correlations r_{ab} between the monthly means are always smaller than those r_{AB} between the annual means. That the coefficients r_{AB} are smaller for the three groups (chosen as in § 7) than for all years was to be expected, since the corresponding distribution of dots in the groups was simply obtained

TABLE 14—*Standard deviations and correlation-coefficients for sunspot-numbers R and magnetic activity u_1, 1872 to 1930*

Item	Sunspot-numbers R					Magnetic activity u_1				
	Dev'n	High	Medium	Low	All	Dev'n	High	Medium	Low	All
Mean values	A_0	66.3	40.7	9.8	38.9	B_0	68.7	50.8	31.7	50.4
Standard deviations:										
Annual means	σ_A	18.3	15.1	8.7	27.4	σ_B	9.0	4.8	7.2	15.9
Monthly means	σ_a	24.4	21.5	10.4	30.5	σ_b	21.5	18.6	14.0	23.8
Monthly departures	σ_α	16.1	14.9	6.1	13.1	σ_β	19.5	17.9	11.9	16.7
Ratios k	k_α	0.88	0.99	0.70	0.48	k_β	2.17	3.73	1.65	1.05

Correlation-coefficients

Item	High	Medium	Low	All
Number of years	20	19	20	59
Correlation for annual means, r_{AB}	+0.530	+0.601	+0 569	+0.884
Correlation for monthly means, r_{ab}	+0.301	+0.365	+0.377	+0.654
Correlation for monthly departures, $r_{\alpha\beta}$	+0.234	+0.378	+0.264	+0.292

by dividing the diagram of Figure 14 by two horizontal lines at $u_1 = 57.5$ and $u_1 = 42.5$ into three horizontal strips. This reduces σ_B in the groups, and explains the high ratios $k_\beta = \sigma_\beta/\sigma_B$. It is also characteristic that the ratios k_α for R are all smaller than the ratios k_β for u_1, indicating

a smoother run, or higher after-effect in the monthly means of sunspot-numbers as compared with magnetic activity; this is already noticeable in Figure 3.

The transition from the correlation-coefficient r_{AB} for the annual means to that for the monthly means, r_{ab}, which has just been discussed arithmetically, is equivalent to the transition from Figure 14 to Figure 16 and can therefore be described graphically, as indicated for three years (of high, medium, and low activity) in Figure 17. The large dot, representing the annual means for 1918 in the left-hand graph of Figure 17, is the mass-center of the 12 dots representing the months; or, otherwise expressed, the dots for the monthly means are formed by an "explosion" of the dot for the annual means, resulting for the three years in the three "stars" in Figure 17. In the left-hand graph of Figure 17 the distribution of the annual means determines σ_A, σ_B, and r_{AB}, and

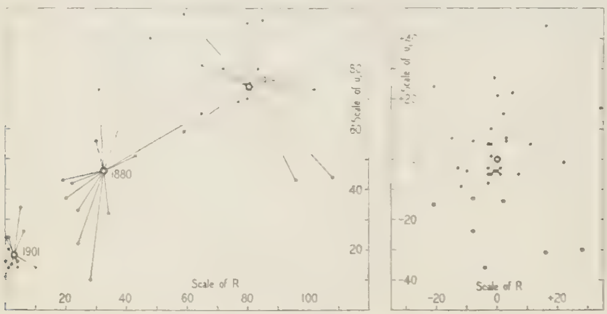


FIG. 17—Relative sunspot-numbers R and terrestrial-magnetic activity u_1 in year of high activity (1918), medium activity (1880), and low activity (1901), demonstrating relations between correlation-coefficients for annual means, monthly means, and monthly departures; monthly and annual means at left and monthly departures from annual means at right

the distribution of the monthly means determines σ_a, σ_b, and r_{ab}; superposition of the three "stars," with the annual means as center, gives the distribution in the right-hand graph of Figure 17, which determines σ_α, σ_β, and $r_{\alpha\beta}$.

The correlation-coefficient r corresponds to a given distribution of dots in the following manner: Suppose the scales of the two variables (say x and y) being normalized, that is, chosen so that their standard deviations are equal; this is graphically realized by extending or compressing the graph (like Fig. 17) in the direction of one axis. If then, according to the methods of least squares, ellipses of equal frequency are constructed, with their axes along the 45° lines $x=y$ and $x=-y$, the ratio of the axis along the diagonal $x=y$ to the axis along the diagonal $x=-y$ is, for each ellipse, equal to

$$(29) \qquad \sqrt{(1+r)/(1-r)}$$

for instance, equal to 2 for $r=0.6$ and equal to 1 (circle) for $r=0$. The ellipticity of the distribution is therefore a measure for the correlation. These indications will be sufficient help for visualizing the content of the

analytical discussion given above and of Table 14: Figure 17 makes it clear how important are the ratios k_1 and k_2 between the amounts of the "explosion" of the annual means and the scattering of the annual means for the combination of r_{AB} and $r_{\alpha\beta}$ into r_{ab}. And the reasons for the introduction of the u_1-measure (§ 6) may now be simply summarized in the statement, that the greater scattering of the monthly means of the original u-measure would have implied greater values of k and therefore smaller correlations for the monthly means.

σ_β is, of course, the same quantity that was designated by σ in equation (6), § 7. We might have obtained slightly higher correlations between u_1 and R if we had used monthly means of u_1 which were freed from the annual variation, and which had therefore the standard deviation σ' as defined in (6). However, the numerical differences between σ and σ', as given in § 7, are too small to make this elimination necessary.

In conclusion, it must be mentioned that in certain selected groups of years, at the end of a sunspot-maximum, the correlations r_{ab} between the monthly means of R and u_1 are much poorer than Table 14 indicates for the whole series. The correlation-coefficient r_{ab} for the 36 monthly means 1918-20 is only +0.06 and for 1928-30 is −0.01. This remarkable obliteration of the otherwise close relations between sunspots and magnetic activity in certain intervals is not removed by the use of other measures of solar activity (§ 18) and therefore imposes caution in drawing conclusions from observations in a limited number of years.

17—*The individual 27-day recurrences, 1906-31, and their relation to sunspots*

The main results of the extensive work of C. Chree and J. M. Stagg[40] were that disturbed and quiet magnetic conditions tend to recur after intervals of 27 days, and that no systematic lengthening or shortening of this interval could be detected when groups of years with many or few sunspots or with high or low sunspot-latitudes were formed. Contrary to opinions held by H. Deslandres, no trace was found of the existence of any disturbance-interval which is an exact submultiple of 27 days, that is, of any symmetrical pattern of the active regions around the Sun's circumference. According to W. M. H. Greaves and H. W. Newton[41] the recurrence-characteristic is mainly a property of the storms of smaller range, while the intense storms (with an average mean range in the three components over 180γ as recorded at Greenwich) are generally followed neither by another storm nor even by a subsidiary disturbance.

While the investigations just mentioned deal mainly with averages for many cases, it seemed to be of interest to investigate the 27-day phenomenon individually. Therefore, a day-by-day record of magnetic activity, as measured by the international magnetic character-figures C, was prepared indicating C by suitable symbols. The record reads like a book. The date of the first day in each row is indicated on the left, each successive row beginning 27 days later; at the end of each row the first nine days of the next row have been repeated in order to emphasize the continuity of the series. For reference, the days in each row are numbered 1 to 27. The symbols were chosen so that there are in all

[40] C. Chree and J. M. Stagg, Phil. Trans. R. Soc., A, **227**, 21-62 (1927); J. M. Stagg, Met. Office, London, Geophys. Mem., **4**, No. 40, 8 pp. (1927). For a review of these papers and others see [illegible].
[41] Mon. Not. R. Astr. Soc., **89**, 641-646 (1929).

about as many black as red symbols on the chart. The values for C to September 1931 have been provisionally derived from the quarterly lists. The years 1906-31 have been arranged in two vertical rows, so that intervals which are 11 years apart appear side by side.

The information which is contained in this arrangement of more than 9,000 symbols will be useful insofar as most days can now easily be assigned to a 27-day sequence of quiet or disturbed days; by *sequences* we mean one of the many vertical columns of symbols of the same or nearly the same kind, which are so conspicuous on the diagram and which demonstrate the 27-day recurrence-phenomenon most convincingly[42]. Some characteristic features may be pointed out[43] [inset (Fig. 18), opposite]:

(*a*) Years of sunspot-minimum are marked by prevalence of red symbols, and years of sunspot-maximum by frequent black symbols. However, there is not a single row of 27 days which contains nothing but black or nothing but red symbols; on the contrary, pronounced sequences of quiet days persist near a sunspot-maximum, for example, in 1917, 1918, and since 1926, and sequences of disturbed days persist near a sunspot-minimum (1911 and 1923).

(*b*) The synodical rotation-period of the Sun's surface, as determined from recurrent sunspots, is 26.9 days on the solar equator, 27.1 days in 10° latitude, 27.5 days in 20°, 28.3 days in 30°, 28.8 days in 35° latitude. Higher levels of the Sun's atmosphere rotate faster and therefore face the Earth after shorter synodic rotation-periods, as shown in Table 15[44]. A recurrence-interval shorter or longer than 27 days would appear in Figure 18 as a gradual shift of the sequence toward the left or right, respectively; from the systematic change in sunspot-latitude during the 11-year cycle (Fig. 15), longer intervals would be expected at the beginning and shorter intervals at the end of a sunspot-maximum. The slight systematic movements in longitude of the spots[45], which depend on their age, are not great enough as to bring about essential differences from the average rotation-period which is proper for the latitude.

A 28-day interval seems to be indicated in the minor disturbances during the second half of 1913 (after day 13), but otherwise the diagram does not show a regular effect of that kind. In fact, 27-day intervals seem to prevail and in long sequences systematic shifts of more than half a day within a solar rotation are rare.

Table 15—*Synodic rotation-periods for different levels of the Sun*

Heliographic latitude	Sunspots	Reversing layer	Calcium-line 4227	*Hα* (near Sun's limb)
°	*days*	*days*	*days*	*days*
0	26.9	26.4	25.9	25.7
15	27.3	27.0	26.0	25.9
30	28.3	28.4	27.0	26.4

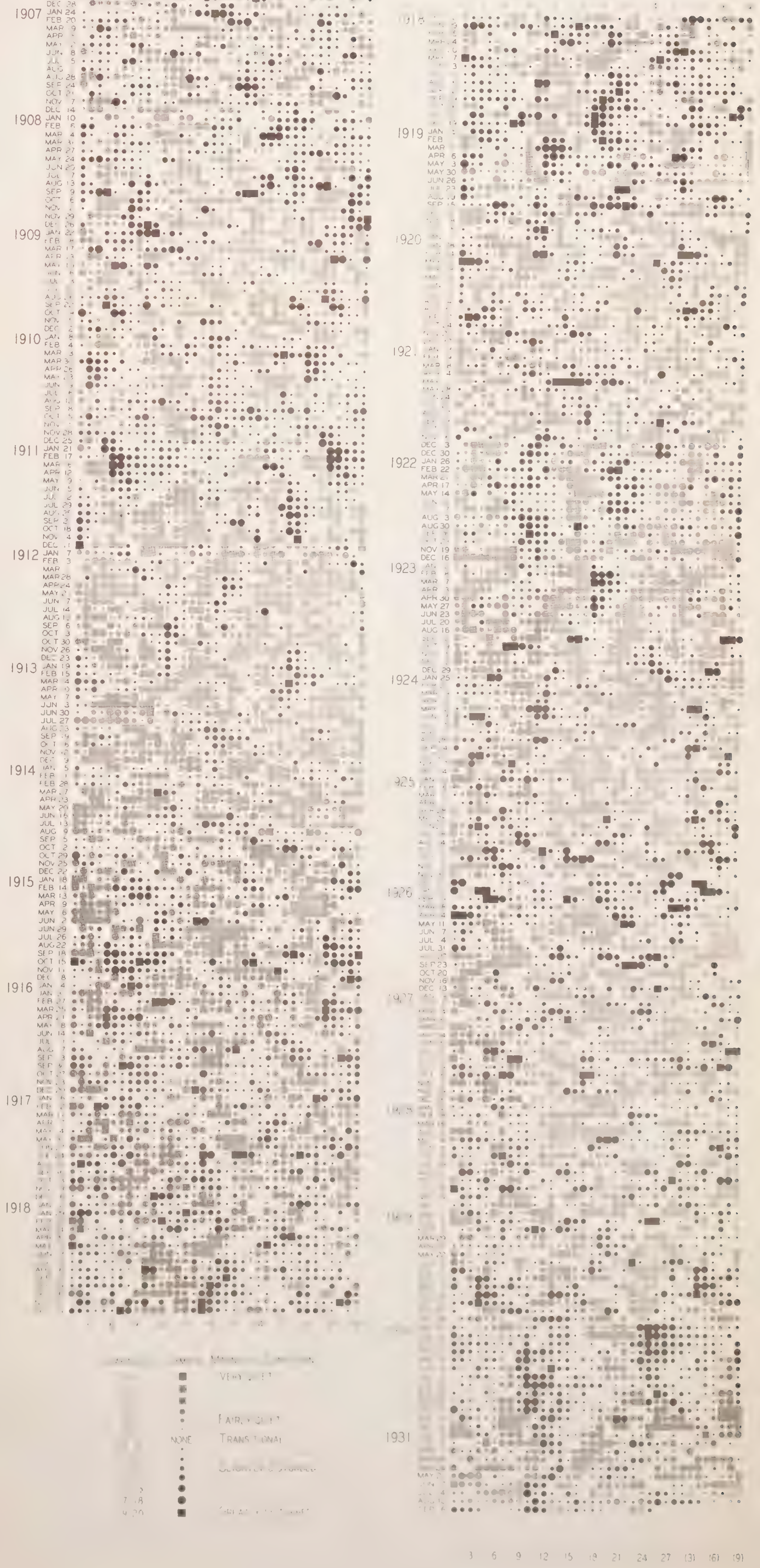
[42] The original diagram was prepared for the Annual Exhibition of the Carnegie Institution of Washington in December 1931.

[43] The solar data in this discussion are taken mainly from the Greenwich photoheliographic results and their annual summaries in Mon. Not. R. Astr. Soc., and from the Astr. Mitt. by A. Wolfer and A. Brunner.

[44] Based on the table of angular velocities in Handbuch der Astrophysik, **4**, 167 (1929).

[45] Greenwich photoheliographic results for 1924, pp. D79-D85.

DAY-BY-DAY RECORD OF
MAGNETIC ACTIVITY



(*c*) Great storms appear often isolated, that is, within an otherwise quiet sequence. Outstanding cases (with $C \geq 1.7$) are the following: September 11-12 and 29-30, November 17, 1908; August 6, 1912; July 1, 1916; August 15-16, 1918 (seems to recur after two rotations); September 22, December 26, 1920; September 14, 1922; September 26-27, 1923; March 5, 1926; October 24-25, 1928; July 10 and October 16, 1929; December 3-4, 1930. Other great storms, however, appear in, or lead, pronounced sequences.

G. E. Hale[46] has recently discussed the cases in which solar eruptions could be connected with the following outbreaks of terrestrial-magnetic storms. In the interval for which Figure 18 is constructed, several of these storms occurred in definite sequences, namely, September 11, 1908; September 24, 1909; January 26 and February 23-25, 1926 (this pair is part of the same sequence). Some of the storms appeared at the end of disturbed sequences and were followed by quiet days, namely, May 14, 1909; June 15, 1915; October 14, 1926.

The solar eruption of November 10, 1916, was perhaps not (as Dr. Hale assumes) without a terrestrial effect, because November 12 had a small but widespread magnetic disturbance ($C = 1.8$). This is interesting because this disturbance has in Figure 18 quite the appearance of the "isolated storms" enumerated above, and for some of which Dr. Maris[29] suggests non-solar origin; about the same statement holds for the three storms listed at the end of the last paragraph. It is, therefore, quite likely that more isolated storms will become linked to strong but short-lived solar eruptions when Dr. Hale's program of continuous solar observations will be realized, so that the solar origin, which for the minor disturbances is guaranteed by their 27-day recurrence, will also be assured for the isolated storms.

(*d*) Especially long sequences seem to occur at the end of the sunspot-maximum, when the spots are near the equator, while the first disturbances of the new cycle are more irregular, giving those parts of the diagram a spotty appearance. The transition from the old to the new cycle is well marked in 1914 and especially in 1923. The fine sequence in the first half of 1923 (day 18), with its sharp recurrences after 27 days, belongs obviously to the old cycle; it is remarkable because *it persists through times* (*in February and May*) *when, for several weeks in succession, not a single sunspot was visible!*

There were no spots on the Sun from April 8 to July 8 (92 days), 1913, and after a small group had lasted from July 9 to 14 there were again no spots from July 15 to August 22 (39 days). "No year since 1810 has been so barren of sunspots as 1913. For seven months (March to September) the Sun was nearly always free from spots."[47] However, sequences of minor magnetic disturbances persist through this interval; the 28-day interval already mentioned is probably due to disturbed regions on the Sun, which were in the same high latitudes (28°) as the few spots seen in June and July.

In 1917, according to A. Wolfer, rhythmic recurrences of spots after one solar rotation are almost entirely absent and spots never lived longer

[46] Astroph. J., **73**, 379-412 (1931); reviewed by W. Grotrian, Naturw., **20**, 55-56 (1932). Methods of recording observations with the spectrohelioscope are discussed by Dr. Hale in Astroph. J., **74**, 214-222 (1931).

[47] Mon. Not. R. Astr. Soc., **75**, 19 (1915).

than through two solar rotations; Figure 18 shows, however, some well-developed disturbed sequences.

The remarkable sequences of 1930 and 1931 will be discussed in § 18.

(*e*) Though often two or more sequences run simultaneously, they do not divide the 27-day interval into regular subdivisions. Even the spotted regions on nearly opposite sides of the Sun, which A. Wolfer points out for the year 1911, are not reflected in magnetic conditions.

"During the year 1922, two-thirds of the spot-groups were confined to one-half of the Sun, between heliographic longitudes 330°−0°−130°. The region between longitudes 130° and 330° contained the remainder, but, with two exceptions, these groups were all very small and usually short-lived."[48] Magnetic conditions again do not correspond to these solar conditions, since two well-separated sequences occurred in 1922.

(*f*) The greatest disturbance on the chart is that of May 13-16, 1921, which was accompanied by the passage of a large naked-eye spot-group on the solar equator through the Sun's central meridian on May 14[38].

(*g*) The determination of the lengths of sequences is somewhat uncertain, but the existence of very long sequences is obvious. Outstanding examples of disturbed sequences ($C \geq 0.8$) are day 9, July 24 1910, to June 13, 1911, 13 rotations[49]; day 9, December 11, 1921, to November 27, 1922, 14 rotations; day 13, December 9, 1929, to March 13, 1931, 17 rotations. Examples of quiet sequences ($C \leq 0.5$) are November 7, 1912, to December 16, 1913, 16 rotations; May 16, 1923, to June 28, 1924, 15 rotations; August 28, 1926, to August 14, 1927, 14 rotations. These and other long sequences persist regardless of season.

This forms an unexpected contrast to the direct solar observations. In her catalogue of recurrent groups of sunspots, 1874-1906, Annie S. D. Maunder[50] says: "Of the 624 instances of recurring groups catalogued, 468 were seen only in two rotations, 118 appeared in three rotations, 25 in four rotations, 12 in five rotations, and in one instance only, and that somewhat doubtfully, did a spot-group survive to be seen in a sixth apparition. Five months is the longest continuous life-history recorded for any group in the whole of the 33 years covered by the catalogue. It is evident, therefore, that a group of solar spots is essentially a short-lived phenomenon."

Of course, the longer duration of disturbed sequences in magnetic activity may in some few cases be caused by a more or less accidental continuation of a spot-group in the northern solar hemisphere by one in the same longitude in the southern hemisphere, but it is more satisfactory to mention, in this respect, the longer life of faculae (see § 18).

(*h*) If the time T of passage from the Sun to the Earth would be constant for all corpuscular streams, then our diagram could be conceived as a chart of the Sun, indicating the heliographic longitude of the *active regions on the Sun*—which we shall call here *M-regions*. Several investigators[51] have shown that T may be as high as 3 or 4 days for moderate disturbances, while it may be as low as one day for the great magnetic storms. This latter value is also suggested by the discussion

[48] Mon. Not. R. Astr. Soc., **84**, 31 (1924).

[49] The two long disturbed sequences in 1911 have been discussed by G. Angenheister, Terr. Mag., **27**, 69-71 (1922).

[50] Greenwich photoheliographic results for 1907, Appendix, p. 6.

[51] Ch. Maurain, Ann. Inst. Phys. Globe, Paris, **5**, 86-96 (1927); J. M. Stagg, Met. Office, Geophys. Mem., No. 42 (1928); W. M. H. Greaves and H. W. Newton, Mon. Not. R. Astr. Soc., **88**, 556-567 (1928).

of G. E. Hale[46]. Since our sequences mostly consist of minor disturbances, our chart incidentally supports the view that the time T of passage for these, whatever it may be, is certainly fairly constant because otherwise such sharp "fronts" of sequences as in 1923 and 1930 could not occur.

(i) The "width" (w) of the columns which indicate the disturbed sequences varies from comparatively narrow bands (as in 1923) of about two days to broad columns of five or more days (as in 1930). A width $w = 2$ days may often be due to a disturbance of only a few hours' duration, overlapping two successive Greenwich days. If w could be conceived as indicating the extension of the M-region in heliographic longitude, one day would correspond to $360^\circ/27 = 13^\circ.3$.

(j) It is not proposed to test in this paper the 30-day recurrence in the larger storms, found by Adolf Schmidt[52].

18 *The solar indices, 1928-30, compared with terrestrial-magnetic activity*

The identification of the M-regions on the Sun's surface, which are the sources of the persistent corpuscular streams causing the sequences of disturbed days, will now be attempted. From the discussion in the last paragraph it is already clear that the M-regions cannot simply be coordinated to spot-groups; the most convincing argument is that spot-groups have been observed crossing the Sun's central meridian without causing magnetic storms, while good sequences of magnetically disturbed days occurred in times when no sunspots were visible.

The faculae have often been suggested as likely to have greater significance for geophysical phenomena than the spots. In this respect, the concise summary[35] of the Greenwich observations from 1874-1917 may be quoted:

> "The centres of the chief zones of the faculae have a well-defined progression with the solar cycle of about 11 years . . . , in considerable accordance with the latitude progression of the sunspots. . . . As compared with the spot-zones, however, the corresponding faculae-zones are on the average about 15° broader. The extension is mainly polewards, and . . . made up entirely of small areas of faculae, the largest areas being always confined to the region of the spots.
>
> "In character, the faculae unassociated with sunspots are small, faint areas lasting at the most for two months. This characteristic offers a striking contrast to the faculae connected with sunspots, which develop in a few days into bright and compact masses often covering a great area. These after about two months become faint and more scattered but they can nearly always be discriminated from those which have at no time been seen with sunspots. With large spot-disturbances, the faculae can be recognized frequently for several months.
>
> "The mean percentage area of faculae unconnected with spots as compared with the total area of all faculae is about 10 per cent. This figure increases to about 30 per cent during the minimum years and falls to 5 per cent when the Sun is active.
>
> "An area of very bright, compact faculae indicates that either a spot-group has been very recently connected with it or that one will appear within a few hours.
>
> "The duration of faculae connected with a spot-group is on the average at least three times the length of the accompanying spots, but the proportion is a very variable one. Generally speaking, the faculae of large spot-groups as compared with those of smaller groups do not last proportionally as long.

[52] Ad. Schmidt, Met. Zs., **26**, 511 (1909); **37**, 166 (1920); **42**, 240 (1925). Astr. Nachr., **214**, 409-414 (1921). G. Angenheister, Terr. Mag., **27**, 57-79 (1922). L. W. Pollak[4].

"The faculae frequently act as a connecting link between successive spot-disturbances in the same region. Near the maximum of the solar cycle, some of these centres have been traced without intermission for over six months and a few for nearly a year.

"Faculae frequently appear in streaks roughly at right-angles to the direction of the Sun's rotation, and have a strong tendency to spread from a spot-disturbance for several degrees in latitude. This feature contrasts with the spots themselves which invariably stream out in longitude, whilst there is little trend in the direction of latitude.

"The faculae change form rapidly, and individual features can seldom be recognized at successive appearances at the Sun's limbs. The groups of faculae considered as entities are, however, more stable than groups of spots. . . . The regularity of statistics of sunspots is largely disturbed by the fact that we have an imperfect record of the spots owing to the Sun's rotation. The longer life of the faculae tends to smooth this.

"The investigation of the faculae has brought more strongly than was anticipated the very close connection between them and the sunspots. There are no spots without faculae, and no extensive areas of faculae without spots.

"There is a zone of polar faculae in both hemispheres . . . about latitude 70°, . . . small, short-lived, detached flecks. Their appearance seems to be somewhat erratic and shows no pronounced relationship with the solar cycle . . . ; they are not associated with the polar prominences."

From this description it seems difficult to separate purely statistically the geophysical influences of sunspots and faculae; only the greater persistence of the faculae is significant in connection with the long sequences in magnetically disturbed days.

More definite results were expected from the use of the daily character-figures of solar phenomena, to which we shall refer here as *solar indices*[53]. These indices denote the daily area and intensity of calcium-flocculi and the bright and dark hydrogen-flocculi by numbers 0 to 5, "0" representing absence or rarity of flocculi and "5" extreme abundance and intensity. Each observatory states these numbers separately; we shall use here the daily mean. As geophysically more important, we shall use the indices for the central zone only, which in 1928 was the sector between meridians situated 30° on either side of the central meridian, and in 1929 and 1930, a central circular surface of a semi-diameter of the Sun's disc; no distinction was found necessary because of this change of zone.

It is well realized that the solar indices represent the solar activity not nearly as completely as the international magnetic character-figures represent magnetic activity. The main reasons are the smaller number of cooperating observatories (about 6 against over 40), frequent interference of atmospheric conditions, and the small number of observations per day at each observatory (mostly one, instead of the continuous magnetic records). Some days have passed without a single solar observation at any observatory. The corrected solar indices, as given by Howell C. Brown[54], are used here and found satisfactory, as will be seen later; of course, the solar indices, which are derived in a similar way as the international magnetic character-figures, therefore have the same limitations as were discussed in § 2.

For all the material available, that is, the three years 1928-30, the international magnetic character-figures C, the relative sunspot-numbers

[53] Internat. Astr. Union, Bull. for character-figures of solar phenomena, published quarterly by the Eidgenössische Steruwarte, Zürich, since 1928. For a discussion of solar physics see, for instance, the article of G. Abetti, Handbuch der Astrophysik, **4** (1929).

[54] Terr. Mag., **35**, 237-244 (1930); **36**, 345-348 (1931). The establishment of another standard series of solar indices is announced by A. Brunner in the Bull. for character-figures of solar phenomena, No. 13, 52-53 (1931); we shall see later that other methods of reduction are not likely to affect our conclusions. Though these conclusions will indicate certain limitations in the expected value of the solar indices, they are not to be misinterpreted as criticisms of the general scheme of the solar character-figures—without which, in fact, some results of this paper could not have been derived.

R_c for the central zone, and the indices for bright $H\alpha$-lines were first compared day by day, the latter being chosen as representative of the conditions in a high level in the Sun's atmosphere. In order to make this comparison as clear and as free from bias as possible, it was decided to prepare 27-day recurrence-diagrams in the manner of Figure 18, and to assign six symbols, called group-indices "0" to "5," so that in each of the three diagrams, for C, R_c, and $H\alpha$, about the same number of symbols of each kind occurred. The medium group "2" was made the largest, containing about 28 per cent of all days, while the extreme groups "0" and "5" contained only 13 and 12 per cent, and the groups "1," "3," and "4" about 16 per cent each. On the basis of frequency-tables, the groups were chosen as indicated in the following table.

Group-index	Magnetic character-figures C	Central sunspots R_c	Bright hydrogen lines $H\alpha$
0	0.0, 0.1	0	0.0–0.3
1	0.2, 0.3	1–13	0.4–1.0
2	0.4–0.7	14–28	1.1–1.8
3	0.8–1.0	29–42	1.9–2.4
4	1.1–1.3	43–57	2.5–3.1
5	1.4–2.0	≥ 58	≥ 3.2

The diagrams are shown in inset opposite p. 48 (Fig. 19); a few days for which no data for R_c or $H\alpha$ are available had to be left blank. Since the charts are drawn in the same manner as Figure 18, the diagram for C in Figure 19 is only a somewhat generalized repetition of the corresponding interval in Figure 18 and shows therefore the same 27-day sequences. Such sequences are also pronounced in the two diagrams for R_c and $H\alpha$, which moreover show the general decrease in solar activity throughout the interval. The interesting feature of Figure 19 is the close resemblance of the diagrams for R_c and $H\alpha$: each quiet or disturbed sequence in one diagram can be recognized in the other. *But no such resemblance appears between the diagram for C and either of the others*, even if the possibility of a general lag of several days in taken into account.

A statistical calculation confirms this impression; because of the better observational conditions in the months April to October, as indicated by fewer omissions of days in the original tables, only the 548 complete days of these months, 1928-30, were considered. On 65 of these days C belonged to group "0"; this group has therefore the relative frequency $p_0' = 65/548 = 0.118$. The other relative frequencies were obtained in a similar way and are shown by the following table.

Group index	0	1	2	3	4	5
C	0.118	0.153	0.285	0.168	0.159	0.117
R_c	0.132	0.184	0.307	0.162	0.093	0.122
$H\alpha$	0.117	0.170	0.268	0.185	0.146	0.114

The relative frequency of days, say, in group "4" in C is $p_4' = 0.159$, and of days in group "0" in R_c is $p_0'' = 0.132$. If C and R_c were entirely independent, the relative frequency $q_{4,0}$ of days, which belong at the same time to group "4" in C and group "0" in R_c, would be expected to be equal to the product $p_4'p_0'' = 0.159 \times 0.132 = 0.0210$, and the number of

such days $m_{4,0}=0.0210\times 548=11.5$. By actual count, $n_{4,0}=11$ such days were found. The ratio $n_{4,0}/m_{4,0}=q_{4,0}/p_4'p_0''$ is 1.0 in this case, that is, the observed number of days is equal to the number which would be expected if C and R_c were independent. Two quadratic matrices for these ratios, one combining R_c and C, the other combining R_c and $H\alpha$ have been reproduced in Table 16; these are, of course, equivalent to the usual correlation-tables, which were, however, not immediately applicable in their usual form, because the nature of the material made groups of unequal size necessary. The contrast between the matrix for the combination R_c and C and the matrix for R_c and $H\alpha$ is striking—in the first case irregular and accidental oscillations around the value 1.0, indicating lack of correlation, and in the second case strong correlation. The correlation-coefficient between the daily group-indices for

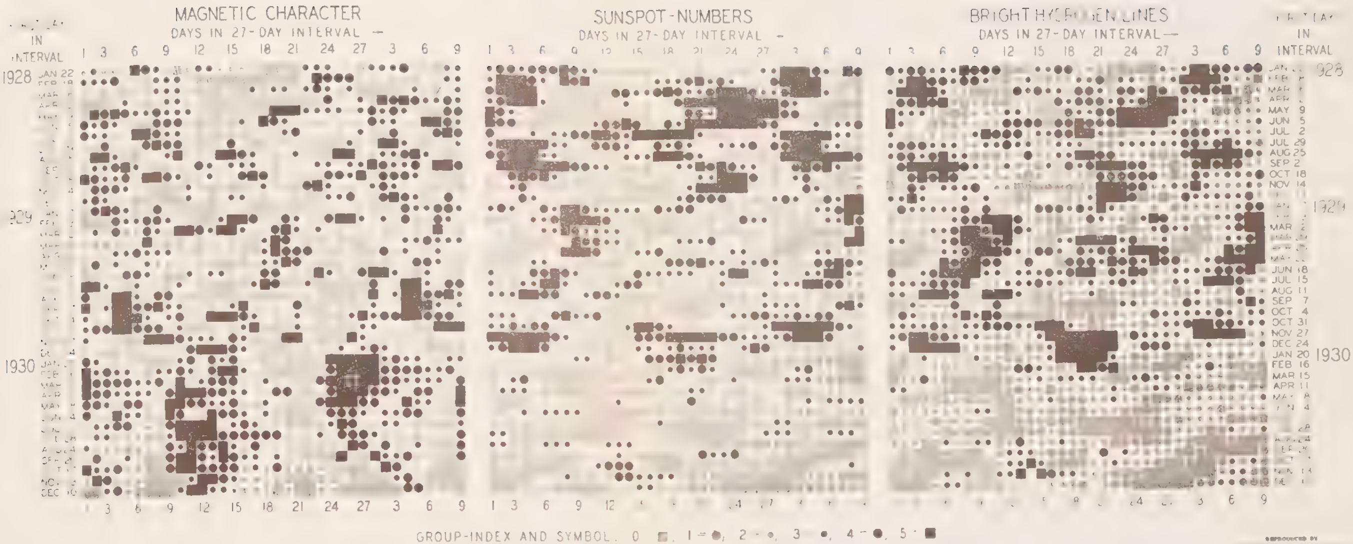
TABLE 16—*Ratios observed number days of groupings of sunspot-numbers Rc, of magnetic characters C, and of bright Hα-lines, to numbers calculated assuming the phenomena independent, months April to October during 1928-30*

Sunspot-number R_c	Magnetic character C						Bright $H\alpha$-lines					
	0	1	2	3	4	5	0	1	2	3	4	5
0	.7	1.2	1.2	.7	1.0	1.0	5.2	1.6	.4	.2	.0	.0
1	.8	.8	.9	1.2	.8	1.3	1.3	1.8	1.6	.4	.4	.0
2	1.0	.9	1.0	.9	1.2	1.0	.3	1.4	1.4	1.3	.6	.2
3	1.7	.5	1.1	.6	1.1	1.0	.0	.2	1.3	1.5	1.1	1.7
4	1.1	1.9	.5	1.3	.5	1.0	.0	.0	.3	1.7	2.5	2.1
5	.8	1.3	1.0	1.6	.6	.5	.0	.1	.0	.9	2.7	3.8

R_c and $H\alpha$ is as high as $+0.745$, while that between Rc and C is -0.080, practically 0, because the standard error of the correlation-coefficient, which for 548 independent pairs would be $1/\sqrt{548}=0.043$, is certainly higher (because values for successive days are not at all independent), perhaps $1/\sqrt{150}=0.08$. An attempt to correlate daily values of R_c with values of C on preceding days, and thereby to get an estimate of the time T of passage for the solar streams, was abandoned, since the correlation-coefficients could be only small, and the methods used by Stagg and Maurain[51] are more suitable for determining the lag T between R_c and C.

Our main result is, that, *in spite of the possibly unsatisfactory observational material or its reduction, the sunspot-numbers and the solar indices for bright Hα-lines are so highly correlated that the latter can hardly be expected to give better results in comparisons with any geophysical phenomena than the former. In particular, the M-regions of the Sun, which are so strongly indicated by magnetic activity, and which in many cases cannot be identified with sunspot-groups, also cannot be associated with regions showing bright Hα-lines.*

That the other solar indices are also closely correlated with the sunspot-numbers is shown in the following Table 17 of correlation-



MAGNETIC CHARACTER
DAYS IN 27-DAY INTERVAL
SUNSPOT-NUMBERS
DAYS IN 27-DAY INTERVAL
DAYS IN 27-DAY INTERVAL
IN INTERVAL
1928
1929
1930
GROUP-INDEX AND SYMBOL

coefficients for all the 36 monthly means that are available at present. In the designation used in § 16, they are coefficients r_{ab}. All the correlations between the sunspot-numbers, and the indices for bright and dark $H\alpha$-flocculi and calcium-flocculi are high; lesser correlation is obtained with the ultraviolet radiation. The correlation between terrestrial-magnetic activity u_1 and all solar indices is negligible; contrary to expectation, the new indices fail completely to improve the poor correlation between u_1 and R which was found (§ 16) to be peculiar to the period 1928-30. This confirms the impression already obtained from the daily $H\alpha$-indices. *Terrestrial-magnetic activity reveals therefore*

TABLE 17—*Correlation-coefficients between the 36 monthly means, 1928-30*

[u_1=terrestrial-magnetic activity; C=international magnetic character-figures; R_c relative sunspot-numbers in central zone; bright $H\alpha$=character-figures for bright $H\alpha$-flocculi in central zone; dark $H\alpha$=character-figures for dark $H\alpha$-flocculi in central zone; Ca=character-figures for calcium-flocculi in central zone; UV=intensity of the ultraviolet solar radiation—ratio ultraviolet ($\lambda=0.32\mu$) to green ($\lambda=0.50\mu$)]

Element	u_1	C	R_c	Bright $H\alpha$	Dark $H\alpha$	Ca	UV
u_1	....	+0.36	−0.02	0.00	+0.02	−0.08	−0.07
C	+0.36	....	−0.44	−0.46	−0.26	−0.59	−0.05
R_c	−0.02	−0.44	....	+0.86	+0.75	+0.86	+0.11
Bright $H\alpha$	0.00	−0.46	+0.86	....	+0.73	+0.90	+0.24
Dark $H\alpha$	+0.02	−0.26	+0.75	+0.73	....	+0.73	+0.35
Ca	−0.08	−0.59	+0.86	+0.90	+0.73	....	+0.33
UV	−0.07	−0.05	+0.11	+0.24	+0.35	+0.33	....

NOTE—Standard errors of these coefficients are $(1-r^2)/6$, that is, 0.17 for $r=0$ and 0.05 for $r=0.85$.

solar influences—recognized as such by the 27-day recurrences—which cannot be traced in the direct astrophysical observations.

G. E. Hale[46], in his recent discussion of the work of the spectrohelioscope, concludes that astrophysical observational means have been very inadequate in the past, and advocates that $H\alpha$-photographs be taken at half-hour or shorter intervals throughout the day. The present writer is convinced that such a more or less continuous spectrohelioscopic watch will bring the astrophysical observations more in line with the well-organized records of terrestrial-magnetic observations; by registering a greater number of the sudden solar flares[55], it will be possible to collect, in the course of some years, more cases of individually coordinated solar and magnetic phenomena.

These solar observations will also help to decide whether the solar streams are nearly continuous or whether they consist of more or less separated clouds of particles which the active solar regions emit intermittently; in the latter case, 27-day recurrence as expressed in Figure 18

[55]See, for instance, Provisional solar and magnetic character-figures of Mount Wilson Observatory, published quarterly in this JOURNAL since **35**; or the observations of solar flocculi made with the spectrohelioscope at Greenwich, Mon. Not. R. Astr., **91**, 593-600 (1931).

suggests that the intervals between successive eruptions must be of the order of one day or less. As to the daily solar indices, however, they are already, even in their present deficient form, so closely correlated to sunspot-numbers that there is not much hope that even more complete observations will give them much additional value for recognizing the solar M-regions which the minor magnetic activity (C between say 0.8 and 1.6) so strongly suggests.

The small correlation between u_1 and C, and the negative correlations between C and the solar indices (Table 17), are probably due to a shift in the character-estimation C, as indicated in § 13. The negative coefficients were then simply due to the spurious increase of C during an interval of declining solar activity, and should be expected to come nearer to zero by using correlation $r_{\alpha\beta}$ between monthly departures (§ 16), since these should be less vitiated by the shift of the scale. In fact, the coefficients $r_{\alpha\beta}$ are $+0.42$ between C and u_1, -0.04 between C and R_c, -0.29 between C and Ca; that is, all are algebraically higher than the corresponding coefficients r_{ab} in Table 17.

A reservation seems appropriate since the discussion of this paragraph was based only on three years of observations. However, it will take some time before more material will be available, and the chief result cannot be disputed, that namely, in an interval in which the sunspot-numbers failed conspicuously to show relations to magnetic activity, the other measures of solar activity did not do better.

SUMMARY

(a) The conception of terrestrial-magnetic activity is discussed, with special regard to the daily international magnetic character-figures C. As an objective measure for the average activity of longer intervals, such as months and years, the day-to-day change (or interdiurnal variability) of the daily means of horizontal intensity is proposed because of its uniformity in the non-polar regions, and the u-measure of activity is based on it. [u is the average change from day to day, regardless of sign, of the horizontal intensity at the magnetic equator, expressed in the unit $10\gamma = 0.0001$ c. g. s.] Monthly means of the u-measure derived by combining the results of several observatories are given for the series 1872 to 1930, and, in annual means, extended backward to 1835.

(b) The relations between the changes of energy of the magnetic field and some measures of magnetic activity are briefly discussed.

(c) For use in certain statistical investigations, a new u_1-measure of activity is derived from the original u-measure. For u_1, a function of the monthly means of u is chosen, the frequency-distribution of which resembles that of the sunspot-numbers. The advantage of u_1 over u is that it represses somewhat the irregular influence of exceptionally violent magnetic storms.

(d) The annual variation of terrestrial-magnetic activity and of sunspot-numbers is discussed; certain tests for periods of general form or of the form of sine-waves (harmonic dial, probable-error circle) are described and applied. Only the semi-annual wave of magnetic activity, with maxima near the equinoxes, appears to be physically significant.

In different ways it is shown to be improbable that this semi-annual wave is related to the inclination of the Sun's axis towards the ecliptic.

(*e*) Apart from a general, but not exclusive preference for the equinoctial months, magnetic storms have not returned year after year on specific dates.

(*f*) The correlations between the annual means of various measures of terrestrial-magnetic activity (u_1-measure, international character-figures) and of solar activity (relative sunspot-numbers, areas of sunspots and of faculae) are discussed and the ensuing merits of the various measures are estimated. Linear relations are used to test the homogeneity of the series. Among the noticeable discrepancies are the abnormally high areas of faculae in 1892, and of the relative sunspot-numbers in the years 1916-18, which seem to be about 10 units higher than the simultaneous sunspot-areas suggest.

(*g*) Due to the higher heliographic latitude of the sunspots in the beginning of an 11-year cycle, they affect terrestrial-magnetic activity less at those times, that is, less in the ascending phase than in the descending phase of the cycle. This is inferred from an apparent lag of the annual means of magnetic activity behind those of sunspot-numbers, which appears in some cycles.

(*h*) The statistical aspect of correlating monthly and annual means is discussed in general, and for the magnetic activity and sunspot-numbers in particular. The general formulae are illustrated by graphs. While the correlation-coefficient between the monthly means of the u_1-measure and sunspot-numbers for the whole series 1872-1930 is fairly high (+0.65), there are intervals for which the correlation vanishes practically. This is the case for the years 1928-30, in which solar and terrestrial-magnetic activity appeared to vary independently. Correlations of geophysical with solar phenomena may therefore give misleading results, if derived from series shorter than one or two sunspot-cycles.

(*i*) The 27-day recurrence phenomenon in the years 1906-31 is discussed on the basis of a graphical day-by-day record, and in relation to solar phenomena. Sequences of recurrences are pronounced, especially in the minor degrees of magnetic activity (international character-figures between, say, 0.8 and 1.6), and are often much longer than observations of recurrent sunspots would suggest. From this discussion we infer the existence of certain restricted areas of the Sun's surface which are responsible for terrestrial-magnetic disturbances, and which we propose to call *M*-regions. They appear to be more long-lived than sunspots. The identification of the *M*-regions with sunspots or other solar phenomena is possible in some cases only, while in many cases the *M*-regions lead, so to say, an independent life.

(*j*) The introduction of the new character-figures for solar phenomena (solar indices), available since 1928 for bright and dark hydrogen lines and for calcium-flocculi, does not improve the relations between terrestrial-magnetic and solar phenomena as already obtained by using the relative sunspot-numbers; in particular, the *M*-regions cannot be coordinated to any of the solar phenomena which are expressed in the solar indices. The main reason is found in the strong correlations which exist between various measures of solar activity, and which deprive the new solar indices of their statistical independence.

(*k*) Observations of terrestrial-magnetic activity, especially of the minor disturbances, reveal persistent solar influences—recognized as such by strong 27-day recurrences—which cannot at present be traced in the direct astrophysical observations of the Sun; in this way, they yield supplementary independent information about solar conditions.

The author is obliged to members of the Department who have given material assistance in the preparation of this paper: Mr. Ennis for his work on the diagrams; Messrs. Duvall, Kolar, and Scott for help in the statistical correlations and in computing, and Mr. Hendrix and Miss Ennis for Figures 18 and 19. I am particularly indebted to Mr. J. A. Fleming for valuable suggestions in putting the material and the paper into its final shape.

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A TYPICAL CASE OF VARIABILITY OF THE QUIET-DAY DIURNAL VARIATION IN TERRESTRIAL MAGNETISM AND EARTH-CURRENTS AT WATHEROO

By J. Bartels and W. J. Rooney

Abstract—The small magnetic diurnal-variation recorded at the Watheroo Observatory, Watheroo, Western Australia, on two successive magnetically very quiet days, February 3 and 4, 1929, was noteworthy. This case is discussed as typical for the variability of the quiet-day diurnal-variation. A significant parallelism is found with the diurnal-variation of earth-currents.

The solar diurnal magnetic-variation on magnetically-quiet days undergoes, apart from its changes with the seasons and the sunspot-cycle, irregular or fortuitous changes from day to day. These are of considerable interest for the theory of the diurnal variation and for the possible information which they may give about corresponding changes in the ionization or diurnal movement of the high layers of the atmosphere, or about changes in solar radiation. S. Chapman and J. M. Stagg[1] have studied the phenomenon for several observatories by means of the ranges, while one of the writers is studying the records taken during 1919-30 at the Watheroo Magnetic Observatory in Western Australia of the Carnegie Institution of Washington by means of a new method[2], using harmonic analysis. In the course of this work several remarkable cases were found, a typical one of which may be used here for demonstration, pending the completion of more detailed investigation to be based on several hundred days.

The days used are 24-hourly intervals from Greenwich midnight to midnight, distinguished as magnetically very quiet by international character-figures 0.0 or 0.1. Two such days in succession, February 3 and 4, 1929, attracted our attention by an unusually small variation in declination (D). This could certainly not be an effect of season, since the diurnal variation at Watheroo changes type and range only little during a great part (middle of October to end of February) of the southern summer. In fact, two pairs of quiet days with normal diurnal-variation were readily found, one preceding (January 18 and 19) and the other following (February 14 to 15) the days just mentioned (Fig. 1). The diurnal variation of the vertical intensity (Z) shows the same features as the D-variation, small amplitudes on the middle pair of days and normal amplitudes on the two other pairs. The horizontal intensity H is given for completeness, though the diurnal variation in H is too small on all days[3] to show differences.

It may be added that the whole interval from January 15 to February 5, 1929, was magnetically undisturbed; only one day, January 29, has an international character-figure 0.7, all the others having less. Later, on February 6 and 9, the character-figure went up to 1.3.

We were surprised to find that on these days which were selected only according to their magnetic variation, the earth-current (horizontal

[1] Proc. R. Soc., A, **123**, 27-53 (1929); **130**, 668-697 (1931).

[2] Pub. Nation. Res. Council, Trans. Amer. Geophys. Union, 12th annual meeting, 126-131 (Washington 1931).

[3] The normal diurnal variation on magnetically quiet summer days at Watheroo is shown in Stereogram 2, Terr. Mag., **36**, 192 (1931).

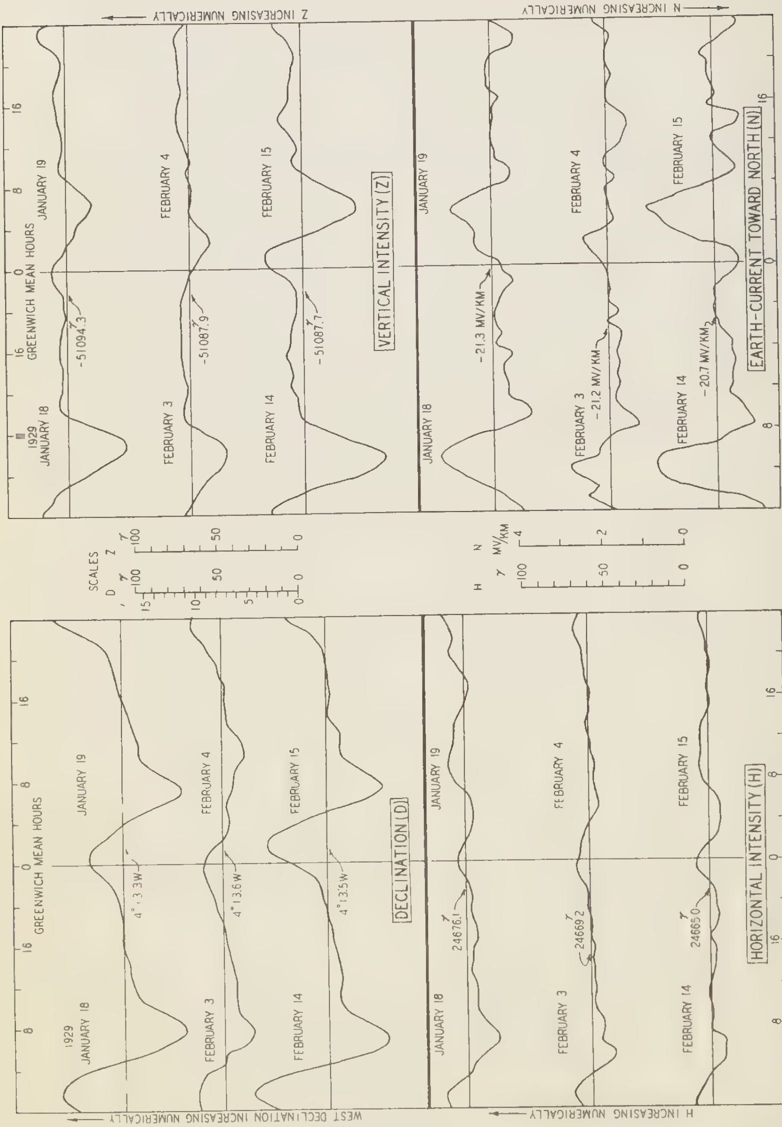

Fig. 1—The exceptionally small diurnal-variations in terrestrial magnetism and earth-currents, February 3 and 4, 1929, as compared with the ordinary diurnal-variations on two earlier and two later days, all six days being magnetically quiet, as recorded at the Watheroo Magnetic Observatory in Western Australia (Greenwich midnight is $7^h.7$ mean local time and mean daily values of zero-lines are as indicated)

potential-gradient, measured in millivolt per kilometer) exhibits in its diurnal variation on the three pairs of days an unmistakable parallelism with the magnetic variations, indicated by small ranges in the middle pair of days, and normal ranges on the two outer pairs. This is shown in Figure 1 by the north component of the earth-current, which at Watheroo is practically equivalent to the total current because of the minuteness of the eastward component there[4].

This parallelism between the changes in the diurnal variations in magnetism and earth-currents, if borne out in other cases, would appear as a strong new argument in favor of a physical connection between both phenomena. For the result of all research in that direction can be comprised in the meager statement that magnetism and earth-currents are disturbed at the same time, while the attempts to demonstrate the nature of their relationship in the diurnal variations have not been satisfactory.

[4] O. H. Gish and W. J. Rooney, Terr. Mag., **33**, 79-80 (1928).

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NOTES

(See also pages 62 and 77)

1. *Fifth Pacific Science Congress*—Official notification has been made through the National Research Council of Canada, that, owing to unfavorable economic conditions prevailing throughout the world, it has been decided to postpone for one year the Fifth Pacific Science Congress which was to be held at Victoria and Vancouver, British Columbia, May 23 to June 4, 1932. Those who have been invited to contribute papers are requested to proceed with the preparation of their manuscripts and to send their papers to the General Secretary as soon as they are completed. Further information and a draft of the scientific program as now prepared will be issued shortly so that those interested may be informed of the progress made.

2. *Magnetic station in Franz-Josef Land*—A magnetic station has been established in Calm Bay, Hooker Island, by the Arctic Institute of the U. S. R. R. A special non-magnetic pavilion has been erected and the new station has been equipped with instruments for absolute observations as well as with self-recording apparatus.

3. *Aeroarctic*—The third general meeting of the Aeroarctic was held in Berlin, on November 7 to 9, 1931. A number of lectures and reports were presented by members of the Society who took part in the 1931 arctic expedition of the *Graf Zeppelin.* It was also decided, in addition to various articles of strictly scientific character to be contributed by members of the Expedition to various journals, also to issue later, as an Ergänzungsheft to Petermanns Mitteilungen, a general detailed exposition of all the scientific results of the Expedition.

4. *Magnetic station at Mogadiscio, Somaliland*—The Italian National Research Council has decided, in connection with its participation in the work of the second International Polar Year 1932-33, to establish a magnetic station at Mogadiscio, Italian Somaliland. Prof. Mario Bossolasco, of Torino, has been appointed to take charge of this new station. In order to study methods and observatory work, he will visit various observatories in Europe before proceeding to Copenhagen, where he will familiarize himself with the new variometer specially developed there for registering the magnetic elements during the Polar Year. One of these instruments has been purchased by the Italian Government for use at Mogadiscio. In addition, Prof. Bossolasco has already available a Kew magnetometer and a Wild earth-inductor for the absolute measurements. It is especially gratifying to learn that Italy will establish a magnetic station in this part of the world where observations are so greatly needed, and it is to be hoped the observatory may be made a permanent one.

5. *International Polar Year 1932-1933*—The joint resolution authorizing an appropriation of $30,000 to defray the expenses of participation by the United States Government in the Second Polar-Year Program, August 1, 1932, to August 31, 1933, which was passed by the House of Representatives on February 24, 1932, was passed by the Senate on March 14, 1932, and has been signed by President Hoover, thus assuring the establishment of a station in Alaska, so important in the general scheme of international stations. It is planned that the United States Coast and Geodetic Survey will install the station-equipment. The Department of Terrestrial Magnetism will cooperate with the Survey in the work.

At the meeting of the Executive Committee of the Rockefeller Foundation, held on February 24, 1932, the following action was taken in support of the International Polar Year 1932-1933: "*Resolved*, that the sum of forty thousand dollars ($40,000), or as much thereof as may be necessary, be, and it is hereby, appropriated to the International Commission for the Polar Year 1932-1933 for special equipment and expenses incident to its use."

OBSERVATIONS OF MICROPULSATIONS IN THE MAGNETIC RECORDS AT TROMSÖ

By Leiv Harang

In an interesting paper Dr. Bruno Rolf[1] has drawn attention to a number of giant micropulsations registered at Abisko in the period 1921-30. In one case (that of the micropulsations which occurred September 12, 1930) the curves from the Observatory of Aurora Borealis at Tromsö (latitude 69° 39′.8 north, longitude 18° 56′.88 east) are reproduced. During the pulsations of September 12, 1930, an absolute determination of the magnetic elements was taken at Tromsö. As the times of the readings on the theodolite are marked on the curves (the same system of time-marking is used as at the observatories at Godhavn and Lovö), we were able to show that the micropulsations in declination (D), horizontal intensity (H), and vertical intensity (V) had a noticeable phase-difference relative to each other. On noting this we at once devised an arrangement permitting very precise time-marking on the curves. This consisted of a small resistance which was connected in series with the lamps and was short-circuited 1.5 seconds every half-hour by a relay operated from the central clock-work. Thus on the continuous curves every half-hour registered as a small dot. At a distance of 3 mm from the continuous curves we have a discontinuous curve, consisting of marks for every minute and dots for every half-hour (Fig. 1). A description of the system of time-marking will appear in the Observatory's Yearbook now in preparation.

After the pulsations which occurred September 12, 1930, none was observed until September 19 and 30, 1931; all of these showed a relative phase-difference in D, H, and V. Figure 1 shows the micropulsations recorded September 19, 1931. Figures 3 and 4 are microphotos of the pulsations on the original curves.

A study of the variation of the perturbing-vector during *one* of these pulsations should contribute to the explanation of these curious magnetic phenomena. The pulsations occur as waves which oscillate about the quiet progress of the curves. We must therefore suppose the perturbing-vector in each component to be *reversed* during each half-period. Assuming the pulsations to be harmonic, the perturbing-vector is represented by the equations

$$\triangle W = A_D \cos \frac{2\pi t}{T}$$

$$\triangle N = A_N \cos \left(\frac{2\pi t}{T} + \alpha\right)$$

$$\triangle V = A_V \cos \left(\frac{2\pi t}{T} + \beta\right)$$

$$P = \sqrt{\triangle W^2 + \triangle N^2 + \triangle V^2}$$

where α and β are the phase-differences which are to be determined from the microphotos by means of the special time-mark. Table 1 gives the numerical data for the four groups of pulsations observed. The inaccuracy in the determination of the phase-difference between the waves in D and H is supposed to be $\pm 15°$ and between D and V some-

[1] Terr. Mag., **36**, 9-14 (1931).

what greater. Table 2 shows the variation of the perturbing-vector during *one* of the pulsations observed September 12, 1930.

From Table 1 it is evident that the phase-differences between $\triangle W$ and $\triangle V$ in all cases are of about the same magnitude, the phase of $\triangle V$ occurring about 130° before $\triangle W$. The phase-difference between

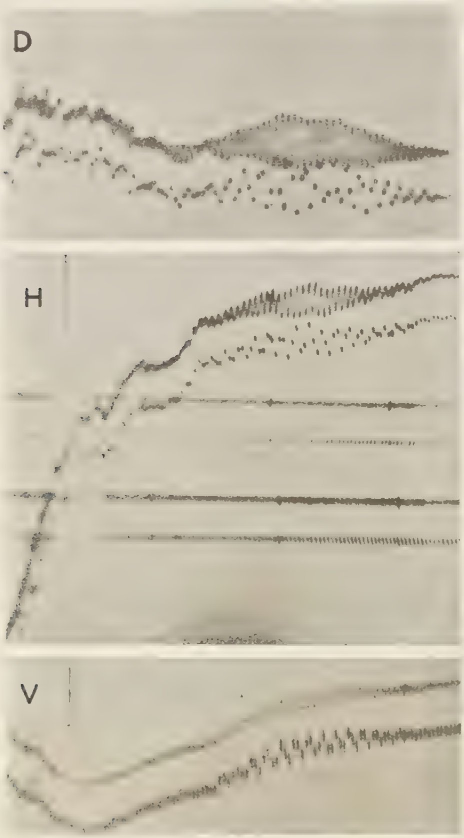


Fig. 1—Pulsations recorded at Tromsö, September 19, 1931

$\triangle W$ and $\triangle N$ is in the first case $-90°$, in the other cases about $+100°$. Figure 2 illustrates the variation of the perturbing-vector, during *one* period, in the horizontal plane and in a vertical plane through the meridian. The direction of rotation may be both clockwise and anti-clockwise.

In his first communications on very small and rapid oscillations in H, Eschenhagen[2] was aware of the possibility that different variometers, owing to different damping, may produce a noticeable influence on the

[2] Berlin, SitzBer. Ak. Wiss., No. 32 (1897).

TABLE 1—*Data for four groups of pulsations at Tromsö*

Date	G.M.T.	A_D	A_H	A_V	Phase-diff. α	Phase-diff. β	Maximum ranges D	Maximum ranges H	Maximum ranges V	Period	No. pulsations
	h m	γ	γ	γ	°	°	γ	γ	γ	*sec*	
Sep. 12, 1930...	9 19	6.5	5.7	4.2	−90	−120	±14	±9	±5	115	26
Sep. 19, 1931...	1 00	8.9	4.4	6.2	123	−129	±10	±6	±6	86	46
Sep. 30, 1931...	8 30	5.8	3.7	...	87	?	±8	±5	±3	118	ca55
Sep. 30, 1931...	9 00	5.8	3.7	3.2	96	−145				118	

TABLE 2—*Variation of perturbing-vector during one pulsation at Tromsö, September 12, 1930*

Perturbing-vector	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	360°
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
ΔW	6.5	5.6	3.2	0.0	−3.2	−5.6	−6.5	−5.6	−3.2	0.0	3.2	5.6	6.5
ΔN	0.0	2.8	4.9	5.7	4.9	2.8	0.0	−2.8	−4.9	−5.7	−4.9	−2.8	0.0
ΔV	−2.1	0.0	2.1	3.6	4.2	3.6	2.1	0.0	−2.1	−3.6	−4.2	−3.6	−2.1
P	6.8	6.3	6.2	6.7	7.2	7.2	6.8	6.3	6.2	6.7	7.2	7.2	6.8

(Column heading: Perturbing-vector for $2\pi t/T$)

shape of the waves in the curves. His simultaneous observations of the pulsations recorded by two different variometers with magnets of different sizes and suspensions indicated, however, that no such effect could be traced. The variometers used in Tromsö were a D-variometer and an H-variometer made by Carl Bamberg of Berlin, and a balance constructed by la Cour[3] (balance de Godhavn). In order to determine

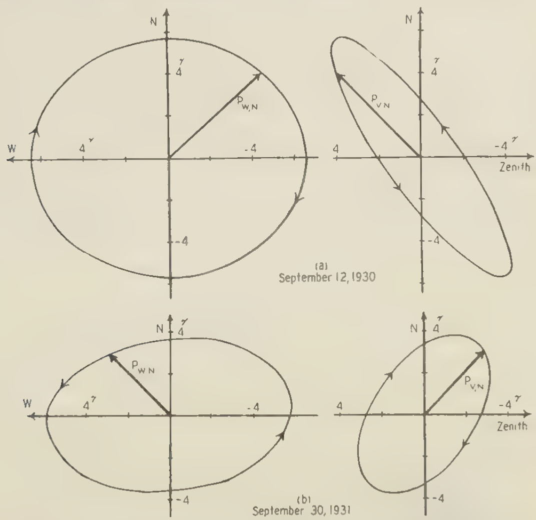


FIG. 2—Variation of perturbing-vector during one period of pulsations recorded at Tromsö, September 12, 1930, and September 30, 1931

[3] Pub. Met. Inst., Comm. Mag., No. 8, Copenhagen (1930).

whether a noticeable phase-difference between the deflections of the different variometers occurs when a harmonically varying perturbing-vector of the magnitude and period of the pulsations mentioned above, is superposed on the Earth's permanent magnetic field, the Helmholtz-Gaugain coils of the three variometers were connected in series

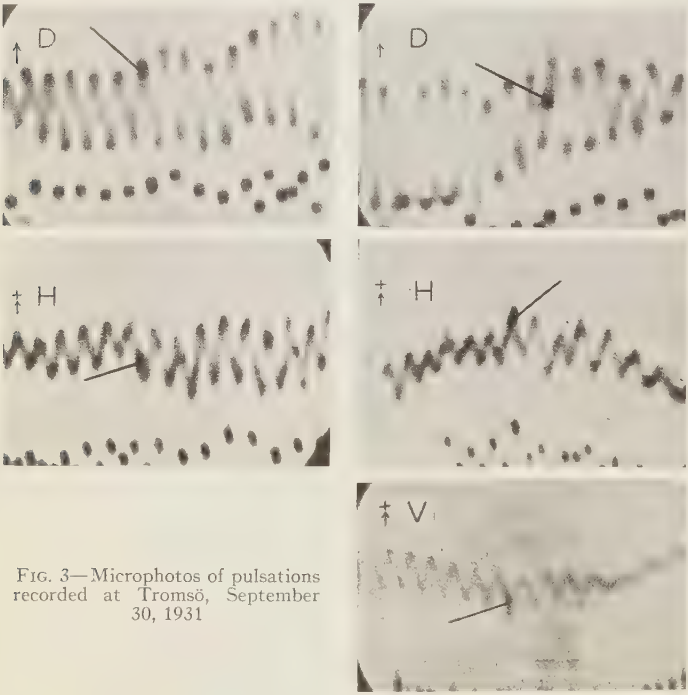


FIG. 3—Microphotos of pulsations recorded at Tromsö, September 30, 1931

and a current which was varied by a great resistance and a reversing switch, was sent through. Using rapid registrations and the method of time-marking mentioned above, no phase-difference between the waves in the three components could be observed.

Rolf[1] has shown that the pulsations of September 12, 1930, occurred locally over the northern part of Scandinavia. How far south the pulsations in September this year can be traced, has not been investigated, but it is probable that they are also of a comparatively local character. In this respect there is a difference between these giant micropulsations and the pulsations observed by Eschenhagen and later studied more extensively by Angenheister[1], who showed that the pulsations in a number of cases were of about the same magnitude at different places on the Earth.

Störmer, during his mathematical investigations of the orbit of an electrically charged particle emitted from the Sun and approaching the Earth, calculated a number of periodic orbits for such a particle[5], and as early as 1906 proposed the electromagnetic effect of clouds of

[1] Göttingen, Nachr. Ges. Wiss., 565-581 (1913).

[5] C. R. Acad. sci., Paris, **142**, 1580-1585 (1906); Zs. Astroph., **1**, 237-274 (1930); Terr. Mag., **36**, 133-138 (1931).

electrically charged particles moving in periodic orbits around the Earth, as a possible explanation of the world-wide Eschenhagen-waves. If we consider only the direct magnetic effect of such clouds, neglecting the magnetic effect of currents induced in the upper atmosphere and the Earth, the perturbing-vector would during a period describe a cone, and thus produce a relative phase-difference between the waves in D, H, and V. As mentioned above the pulsations of September 12, 1930, occurred locally in the northern part of Scandinavia. On account of the relatively local character of the phenomenon it is difficult to explain these pulsations by the magnetic effect of electrically charged clouds

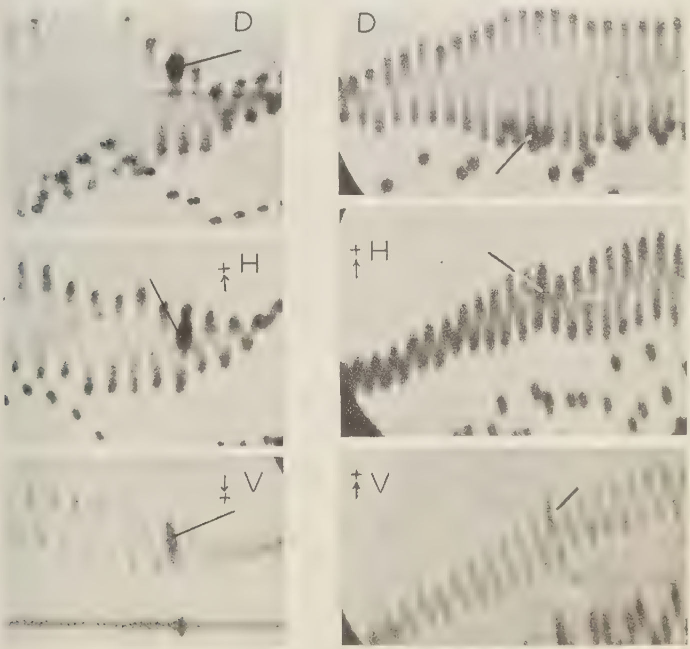


FIG. 4—Microphotos of pulsations recorded at Tromsö, September 12, 1930, and September 19, 1931

moving in the periodic orbits calculated by Störmer, as the distances from the Earth to the orbits are great compared with the dimensions of the Earth, and the pulsations thus should be expected to have the same magnitude over the whole Earth. The effect must be ascribed to currents in the atmosphere above the northern part of Scandinavia, as also suggested by Dr. Rolf.

The study of this class of perturbations would be greatly improved if the phase-difference between the components could also be recorded at different observatories. This can easily be done by using a system of time-marking, similar to that mentioned above, and by using lenses and mirrors of high quality.

OBSERVATORY OF AURORA BOREALIS,
Tromsö, Norway,
October, 1931

NOTES

(See also pages 56 and 77)

6. *Repeat-observations in South America*—The character of the magnetic changes taking place in the general region of the Caribbean Sea and the adjacent land areas makes it very important to secure reoccupations at comparatively short intervals of as many stations as possible. The Department of Terrestrial Magnetism of the Carnegie Institution of Washington has secured a few reoccupations at such accessible points as the Canal Zone, Caracas, Port-of-Spain, and Barbados, from time to time as opportunity offered, but there has been no attempt to secure secular-variation data in the interior of Venezuela since the expedition of A. D. Power in 1913-14. An expedition by Earl Hanson has accordingly been undertaken to supply this lack of information by crossing the region lying south of Caracas and extending to the head-waters of the Orinoco River, and thence by a comparatively short portage to the Rio Negro, a tributary of the Amazon, which provides a direct route to Manaos, Brazil.

Mr. Hanson left Caracas November 10, 1931, and reached San Fernando de Apure 10 days later. After visiting Ciudad Bolivar to complete arrangements for the trip to the interior, he proceeded up the river, arriving at Puerto Ayacucho, Amazonas Province, December 18, and at the Yavita-Pimichin portage January 10, 1932. Facilities for travel throughout this region are very limited, due to the stagnation of the industries upon which the country depends. The conditions along the Rio Negro in Brazil were somewhat better and Manaos was reached February 15. Better success than was thought possible was obtained in recovering the sites of the previous stations in spite of the growth of the tropical jungles, and good secular variation-data should result from this work. Fourteen localities were occupied between Caracas and Manaos, some with auxiliary stations and most of them at least approximate reoccupations of former stations. In spite of the unusual difficulties encountered, results were obtained which are of great importance in the study of secular variation in this region of interesting magnetic changes.

Early in August, 1931, J. W. Green of the Department of Terrestrial Magnetism of the Carnegie Institution, initiated a program of reoccupations of magnetic stations in the West Indies and around the coast of South America, to supplement the work being done simultaneously by Earl Hanson in the interior. After visiting Cuba and Jamaica, he visited the observatory at San Juan and made comparison observations; he then reoccupied magnetic stations in Trinidad, Barbados, the three Guianas, and eastern Brazil, reaching Rio de Janeiro early in January 1932. After comparisons with the observatory standards at Vassouras, he went to Argentina and made similar observations at Pilar and at La Quiaca, besides reoccupying repeat-stations at Bahia Blanca and Mendoza for secular variation. He reached Santiago, Chile, late in March and after making reoccupations of repeat-stations in that country and in Bolivia will finish his work with a comparison of the instruments he is carrying with those of the Carnegie Institution at Huancayo. During the course of this rather extended journey Mr. Green has had the good fortune to meet many investigators and officials of scientific organizations who are interested in the extension of magnetic surveys for secular variation as well as for their practical importance. It is expected that besides improving the coordination of magnetic standards of the several countries his visit will still further establish the spirit of cooperation which has characterized the efforts of all interested organizations in the past and without which the progress made in the study of the magnetic history of this interesting region would have been impossible.

7. *Repeat-observations east of the Mississippi River*—R. G. Ambrose, Magnetic Observer, U. S. Coast and Geodetic Survey, commenced his season's field work with magnetic observations at Vicksburg, Mississippi, March 18. The season's work covers repeat-stations in 18 states, located in the central part of the United States, east of the Mississippi River and from the Canadian border to the Gulf of Mexico. Sixty-five stations will be occupied, 16 of which will be at first-order triangulation-stations near old repeat-stations. These triangulation-stations will be used as future repeat-stations, and it is hoped they will be more permanent than the present repeat-stations. Mr. Ambrose uses a ½-ton panel-body truck, and his work will carry him over a distance of 9,000 miles, in an estimated time of seven months.

TEST-DEFLECTIONS FOR VARIOMETERS AND MAGNETOGRAPHS* (Concluded)

By George Hartnell

39. *Mutual effects, D- and H-variometers*—The mutual potential energy of two suspended magnets in the same horizontal plane is derived from equation (10) by setting $\omega=\beta=0°$. Thus

(135) $$V=C\,[-3\cos(\alpha-\phi)\cos(\alpha-\theta)+\cos(\phi-\theta)]$$

when $C=M_D M_H/d^3$, in which M_D and M_H indicate the magnetic moments of the D- and H-magnets, respectively. In this equation ϕ now indicates the position of the H-magnet, and θ indicates the position of the D-magnet. The mutual torque on D is

(136) $$-(\delta V/\delta\theta)=C\,[3\cos(\alpha-\phi)\sin(\alpha-\theta)-\sin(\phi-\theta)$$

The mutual torque on H is

(137) $$-(\delta V/\delta\phi)=C\,[3\sin(\alpha-\phi)\cos(\alpha-\theta)+\sin(\phi-\theta)]$$

It is assumed that the two variometers are in the magnetic prime-vertical. Hence, when the origin is referred to the center of the D-variometer, $\alpha=-90°$, and when the origin is referred to the center of the H-variometer, $\alpha=90°$. Hence the mutual torque on D is

(138) $$-(\delta V/\delta\theta)=C\,[3\sin\phi\cos\theta-\sin(\phi-\theta)]$$

The torque on D due to H is

(139) $$-M_D H\sin\theta$$

For equilibrium the sum of (138) and (139) becomes zero. Hence the equation of equilibrium for the D-variometer is

(140) $$C\,[3\sin\phi\cos\theta-\sin(\phi-\theta)]-M_D H\sin\theta=0$$

The mutual torque on H is, ($\alpha=90°$), from (137)

(141) $$C\,[\,3\cos\phi\sin\theta+\sin(\phi-\theta)]$$

The torque due to H and the torsion is

(142) $$-M_H H\sin\phi+h\,(\delta-\phi)$$

Hence for the H-variometer

(143) $$C\,[3\cos\phi\sin\theta+\sin(\phi-\theta)]-M_H H\sin\phi+h\,(\delta-\phi)=0$$

It will be convenient to refer the position of the H-magnet to the magnetic prime-vertical by setting $\phi=(90°+\phi')$ and $(\delta-\phi)=(\tau-\phi')$ in (140) and (143), respectively, whence

(144) $$C\,[3\cos\phi'\cos\theta-\cos(\phi'-\theta)]-M_D H\sin\theta=0 \quad (D\text{-variometer})$$

(145) $$C\,[-3\sin\phi'\sin\theta+\cos(\phi'-\theta)]-M_H H\cos\phi'+h\,(\tau-\phi')=0 \quad (H\text{-variometer})$$

Since ϕ' is zero when the D-variometer is away, $-M_H H+h\tau=0$, so that

(146) $$C\,[-3\sin\phi'\sin\theta+\cos(\phi'-\theta)]-h\phi'=0 \quad (H\text{-variometer})$$

*Continued from this Journal, 36, 279-296 (1931).

From (144) and (146) we have respectively

(147) $\tan\,\theta = 2C\cos\phi'/(M_D H + C\sin\phi')$ (D-variometer)

(148) $\tan\,\phi' = C\cos\,\theta/(h+2C\sin\,\theta)$ (H-variometer)

ϕ' being taken as $\sin\phi'$, h is obtained from

(149) $h = M_H S/(\epsilon\times 10^5)$ (HIV, p. 22)

If we neglect terms of the second order, C, ϕ', and θ being small, we shall obtain the familiar equations

(150) $\tan\,\theta = 2C/M_D H = 2M_H/Hd^3$

(151) $\tan\,\phi' = C/M_H S/(\epsilon\times 10^5) = M_D\epsilon\times 10^5/Sd^3$

which are independent of any mutual effects.

In equations (147) and (148), M_D, M_H, and h are given. To solve these equations, compute θ from equation (150) and substitute this value in (148), for the first approximate value of ϕ'. This value is then substituted in (147) for a closer value of θ, which is again substituted in (148) to obtain the second approximate value of ϕ'. We take an example of an extreme case: $M_D = M_H = 50$; $d = 30$ cm; $H = 0.2$; $h = 1.437$; hence log $C = 8.96658$. For first approximation we have from (150), $\theta = 1°\ 03'.7$, which in (148) gives $\phi' = 3°\ 40'.7$. Using this again in (147), θ remains practically unchanged. Equation (151) gives $\phi' = 3°\ 41'.2$. Hence for small magnets, and distances greater than 30 cm, say, the mutual effects of two suspended magnets may be obtained with sufficient accuracy from (150) and (151). With regard to the mutual effects of the D- and H-magnets on diurnal ranges, equations (147) and (148) show that, since the diurnal range in θ and ϕ' is usually less than a degree of arc, the mutual effects are negligible, even in the extreme case given above.

40. *Z-variometer*—The fundamental angles, δ, ξ, and η, for a Z-variometer and the general expression for the mutual potential-energy, V, are given in equations (7), (8), (9), and (10) from which

$$-\delta V/\delta\psi = FM_s\ (3\cos\delta\ \delta\cos\xi/\delta\psi - \delta\cos\eta/\delta\psi)$$

or

(152) $$-(\delta V/\delta\psi) = M_s[(-3F\cos\delta\cos\beta\cos\alpha + F\cos\omega\cos\phi)\sin\psi + (3F\cos\delta\sin\beta - F\sin\omega)\cos\psi]$$

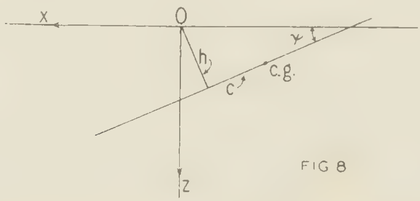


FIG. 8—Diagram of torque due to gravity and to Z and H

The torque due to gravity and to Z and H is derived from Figure 8, where

$$x = -h \sin\psi - c\cos\psi,\quad z = h\cos\psi - c\sin\psi$$

The potential energy of the magnet in the field is $V = -M_sH\cos\psi - M_sZ\sin\psi$. The potential energy due to gravity is $V = -mgz = -mgh\cos\psi + mgc\sin\psi$. The total potential energy due to the field and to gravity is

$$V = -(mgh + M_sH)\cos\psi - (M_sZ - mgc)\sin\psi \tag{153}$$

The torque due to the field and to gravity is

$$-\delta V/\delta\psi = -(mgh + M_sH)\sin\psi + (M_sZ - mgc)\cos\psi \tag{154}$$

Equating this to zero

$$\tan\psi = (M_sZ - mgc)/(M_sH + mgh) \tag{155}$$

We assume $\psi = 0°$ when Z has its normal value, so that $M_sZ = mgc$. The scale-value is

$$-\delta Z/\delta\psi = (M_sH + mgh)/M_s = S \tag{156}$$

When the Z-variometer is deflected by the magnet M_a, the sum of (152) and (154) is zero, from which, since $M_sZ = mgc$

$$\tan\psi = F(\sin\omega - 3\cos\delta\sin\beta)/[-3F\cos\delta\cos\beta\cos\alpha + F\cos\omega\cos\phi - (mgh + M_sH)/M_s] \tag{157}$$

Or neglecting quantities that vanish or are negligibly small in the denominator

$$\tan\psi = F(3\cos\delta\sin\beta - \sin\omega)/S \tag{158}$$

To express this in mm of ordinate, we have the relations $\psi = u'\epsilon$ and $s = S\epsilon \times 10^5$ (scale-value in gammas per mm); thus

$$u' = F_\gamma(3\cos\delta\sin\beta - \sin\omega)/S \tag{159}$$

We shall consider briefly the three coordinate planes. For the xy-plane, $\beta = 0°$, $\cos\delta = \cos\omega\cos(\alpha - \phi)$. Hence from (159)

$$u' = -F_\gamma\sin\omega/S \tag{160}$$

This is zero when the axis of M_a lies in the xy-plane. When the axis of the magnet is vertical, $\omega = 0°$ and

$$u' = -F_\gamma/S = -M_a/d^3S \tag{161}$$

This is independent of the position of the center of M_a in the horizontal plane. The effective component is the vertical component $M_a\sin\omega$.

In the xz-plane, $\alpha = 0°$, $\cos\delta = \cos\beta\cos\omega\cos\phi + \sin\beta\sin\omega$, and (159) becomes

$$u' = F_\gamma[3\sin\beta\cos\beta\cos\phi\cos\omega + (3\sin^2\beta - 1)\sin\omega]/S \tag{162}$$

When M_a is vertical, $\omega = 90°$ and (162) becomes

$$u' = F_\gamma(3\sin^2\beta - 1)/S \quad (A\text{-type, constant distance}) \tag{163}$$

and when M_a is horizontal, $\omega = 0°$

(164) $u' = 3F_\gamma \sin\beta \cos\beta \cos\phi / S$ (B-type, constant distance)

This is zero when $\phi = 90°$, that is, when M_a is perpendicular to xz-plane, for all values of β.

In the yz-plane $\alpha = 90°$, $\cos\delta = \cos\beta \cos\omega \sin\phi + \sin\beta \sin\omega$, and (159) transforms into

(165) $u' = F_\gamma [3 \sin\beta \cos\beta \sin\phi \cos\omega + (3 \sin^2\beta - 1) \sin\omega]/S$

When M_a is vertical, $\omega = 90°$. Then

(166) $u' = F_\gamma (3 \sin^2\beta - 1)/S$ (A-type, constant distance)

and when M_a is horizontal, $\omega = 0°$. Then

(167) $u' = 3F_\gamma \sin\beta \cos\beta \sin\phi / S$ (B-type, constant distance)

This is zero when $\phi = 0°$ for all values of β, that is, when M_a is perpendicular to the yz-plane.

It is interesting to note that whether the center and axis of M_a are in the xz perpendicular-plane ($\alpha = \phi = 0°$) or whether the center and axis of M_a are in the yz-plane, $\cos\delta = \cos\beta \cos\omega + \sin\beta \sin\omega$, we have the same deflections, namely,

(168) $u' = F_\gamma [3 \sin\beta \cos\beta \cos\omega + (3 \sin^2\beta - 1) \sin\omega]/S$

When M_a is vertical ($\omega = 90°$) we obtain from (168)

(169) $u' = F_\gamma (3 \sin^2\beta - 1)/S = M_a (2 \sin^2\beta - \cos^2\beta) \times 10^5 / Sd^3$

When M_a moves with center and axis vertical in xz-plane, along a line parallel to the x-axis, at distance D, we have the relations $D = c$, $d^2 = D^2 + a^2$, $\sin\beta = D/d$, $\cos\beta = a/d$, and (169) becomes

(170) $u' = [M_a/S] [(2D^2 - a^2)/(D^2 + a^2)^{5/2}] 10^5$ (perpendicular primary-type)

When M_a moves with center and axis vertical along a vertical line in xz-plane at distance D, $D = a$, $d^2 = D^2 + c^2$, $\sin\beta = c/d$, $\cos\beta = D/d$, and (169) becomes

(171) $u' = [M_a/S] [(2c^2 - D^2)/(D^2 + c^2)^{5/2}] 10^5$ (perpendicular secondary-type)

When M_a is level ($\omega = 0°$), with axis in xz-plane and moves along a vertical line at distance D, we have the relations $D = a$, $\sin\beta = c/d$, $\cos\beta = D/d$, hence from (164), since $\phi = 0°$

(172). $u' = [3M_a/S] [Dc/(D^2 + c^2)^{5/2}] 10^5$ (parallel type, xz-plane)

When M_a is level ($\omega = 0°$), with axis in yz-plane ($\phi = 90°$), and moves along a vertical line at distance $D = b$, $\sin\beta = c/d$, $\cos\beta = D/d$, and (167) gives

(173) $u' = [3M_a/S] [Dc/(D^2 + c^2)^{5/2}] 10^5$ (parallel type, yz-plane)

It will be observed that, save for the small deflection, M_a and M_s are parallel in the parallel type, xz-plane, and are perpendicular in the parallel type, yz-plane. Thus we see that in the Z-variometer, the different types of deflections arise when the deflecting-magnet is level or vertical.

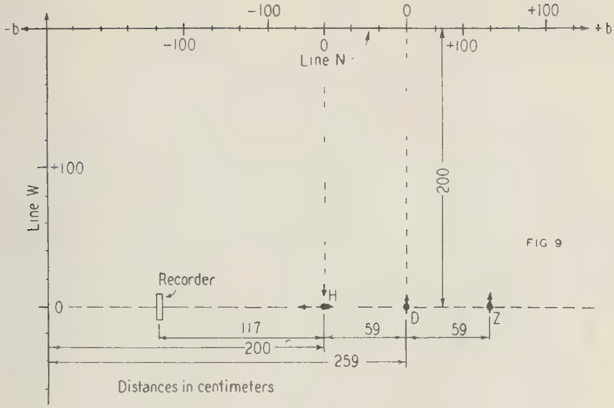


FIG. 9—Sketch of magnetograph set-up

41. *Applications to a magnetograph*—We shall apply some of our equations to a magnetograph of the Eschenhagen type, the plan of which is shown in Figure 9. For this example we have: D-variometer, $M_D=15$ and scale-value $=1'$ per mm; H-variometer, M_H (recording-magnet) $=22$, M_{CH} (compensating magnet) $=90$ at 12 cm from M_H, M_{CH} (sensitivity-magnet) $=90$ at 8 cm from M_H, $\epsilon=1'.5$, and scale-value $=2.85\gamma$ per mm; Z-variometer, M_Z (recording magnet) $=300$, M_{CZ} (compensating-magnet) $=300$, and scale-value $=5.00\gamma$ per mm. The H- and D-variometer magnets are in the same horizontal plane, M_Z being 5.5 cm above and M_{CZ} 7.5 cm below this plane.

42. *Mutual effects of magnets*—The mutual effects of the magnets will be of two kinds, namely, (1) Each variometer will be deflected and (2) the value of H at the center of each variometer will be affected. We shall consider the D-, the H-, and the Z-variometers in turn.

43. *Mutual effects, deflection of D-variometer*—The deflection of the D-magnet due to the H-compensating magnet M_{CH} is found from equation (68) by substituting $M_a=90$, $D=59$, $a=12$, and $H=0.1856$ to be $+4'\ 28''$. The deflection produced by the H-sensitivity magnet is found from equation (23) by substituting $M_a=90$ and $d=67$ to be $-11'\ 06''$. The deflection produced by the recording-magnet M_H is found from equation (150) by substituting $M_H=22$ and $d=59$ to be $+3'\ 58''$. By equation (80) the Z-compensating magnet M_{CZ} produces the deflection $-9'\ 56''$ for $M_a=M_{CZ}=300$, $D=59$, and $C=7.5$. The total deflection-effect is the sum of these, namely, $-12'\ 36''$. This is closer than we can adjust the D-magnet in the meridian by the usual methods.

44. *Effect on horizontal intensity at D-variometer*—Of the H-variometer the compensating magnet is the only one which will affect the horizontal intensity H at the D-magnet. This is computed from equation (43) by substituting $M_a=90$, $x=12$, $y=59$, and $d^2=x^2+y^2$, which gives $\triangle H=+5\gamma$. The field of the Z-recording magnet M_Z at the center of the D-magnet computed from equation (43) using $M_a=300$, $x=0$, $y=59$, $d^2=(59)^2+(5.5)^2$, is -143γ. The total change in the value of H at the D-variometer therefore is -138γ, which is nearly one per cent.

This is an important consideration in scale-value determinations, because the magnetic moment of the scale-value deflector derived from the deflections of the D-variometer will be nearly one per cent smaller than its true value, and consequently the resulting scale-values of the intensity-variometers will be smaller than their true values.

45. *Effect on horizontal intensity at H-variometer*—For the effects on the H-variometer it will be sufficient to compute the change in H, due to the other variometers. The actual deflection may be obtained by dividing these changes by the scale-value. The D-magnet causes a decrease of 7γ in H at the center of the H-variometer magnet as computed in § 43, using $D=59$, $M_a=15$, and $x=0$. The effect of the Z-recording magnet is obtained from the same formula and reduces the value of H by 18γ. Thus H at the H-variometer is reduced by 25γ, and amounts to a deflection of about 9 mm. This decrease in H being constant will not affect the variations recorded by the H-variometer.

46. *Effect on horizontal intensity at Z-variometer*—The only magnet having a sensible effect on H at the Z-variometer is the D-recording magnet. This computed from § 43, using $d^2=(59)^2+(5.5)^2$ and $x=0$, is only a fraction of a gamma—too small to have any effect.

47. *Mutual effect of D- and H-magnets on diurnal variations*—Clearly the D- and H-variometers are the only ones whose variations are likely to be affected. Differentiating equations (47) and (48) we have

$$\delta \tan \theta/\delta\phi' = -(2CM_DH \sin \phi'+2C^2)/(M_DH+C \sin \phi')^2 \tag{174}$$

and

$$\delta \tan \phi'/\delta\theta = -(hC \sin \theta+2C^2)/(h+2C \sin \theta)^2 \tag{175}$$

In our magnetograph $C=M_HM_D/d^3=0.00002$; this is a very small quantity whose square, at least, is negligible. Under this condition

$$\delta \tan \theta/\delta\phi' = -2C \sin \phi' \tag{176}$$

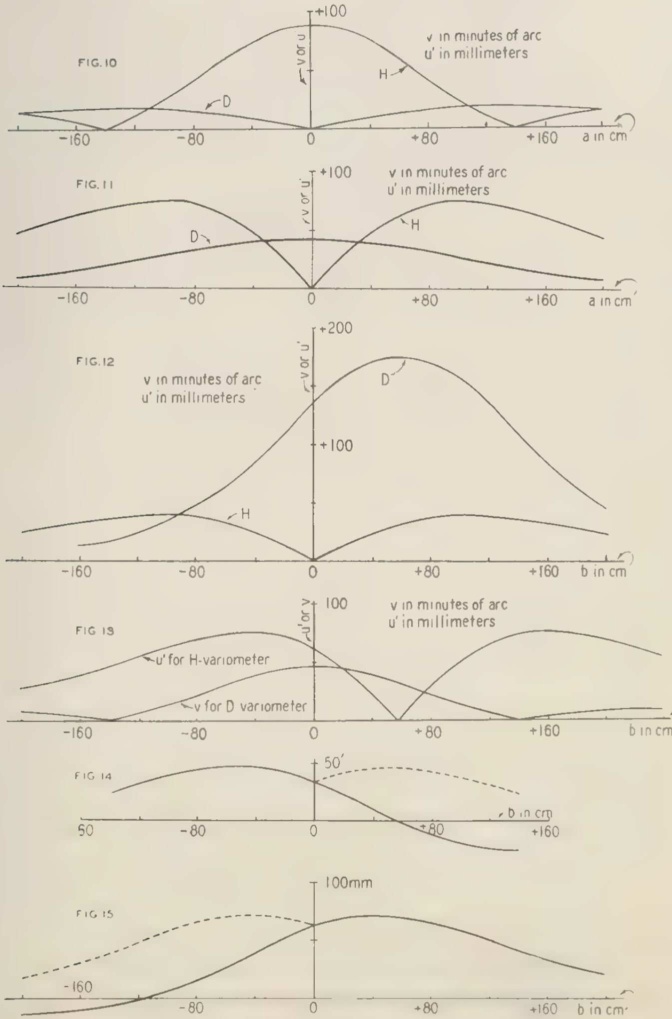
and

$$\delta \tan \phi'/\delta\theta = -C \sin \theta/h \tag{177}$$

Thus taking into consideration the value of C above, and the small range in θ and ϕ', the mutual effect of the D- and H-variometers on the diurnal variations is practically nil. Even in the extreme case given in section 39, the effect on the diurnal variation of D would be only one-third of one per cent, while the effect on the H-variometer would be less than half this amount.

48. *D- and H-deflection curves, west side*—For the purpose of further testing the adjustments of the D- and H-variometers, we shall determine the deflection-curves produced by placing the deflecting-magnet M_a at points along a line west (W) parallel to the meridian, and at distance $D_D=259$ cm and $D_H=200$ cm from the D- and H-variometers respectively, and also along a line north (N) perpendicular to the meridian at distance $D=200$ cm from both variometers. The zero-point on line W is taken at the intersection of the line W and the line passing through D and H. The zero-point on line N is taken north of the D-variometer or two zero-points may be used, north of the D- and H-variometers, respectively. Thus points on these lines will determine the coordinates of the deflecting-magnet. The double deflection-curves obtained by

placing M_a north-south on line W and reversing in each position are shown in Figure 10, for which $M_a = 10{,}000$, $H = 0.1856$ c.g.s., and $s = 2.85$. The curves are symmetrical about y-axis, or line passing through D and H. Therefore, if the variometers are in perfect adjustment, and the line W is parallel to the meridian, points equally distant from zero should give equal deflections. The curves cross at two points and at these points the deflections should be equal for both variometers. The curves



FIGS. 10-15—Deflection-curves computed for various positions of deflecting-magnet

are computed from equations (68) and (113), the points of intersection being obtained by equating these equations; whence using appropriate subscripts for the D- and H-variometers, $\tan v=(3M_a/H)\ [D_Da/(D_D^2+a^2)^{5/2}]$ or $u=(3M_a/H_\gamma\epsilon)\ [D_Da/(D_D^2+a^2)^{5/2}]10^5$ and $u'=(M_a/s)\ [(2a^2-D^2)/(D_H^2+a^2)^{5/2}]10^5$, and

$$(178)\qquad H_\gamma\epsilon/3s=[D_Da/(2a^2-D_H^2)]\ [(D_H^2+a^2)/(D_D^2+a^2)]^{5/2}$$

or

$$(179)\quad \log\ (H_\gamma\epsilon/3s)=(5/2)\ \log\ [(D_H^2+a^2)/(D_D^2+a^2)]+\log\ [D_Da/(2a^2-D_H^2)]$$

This equation may be solved for a by trial. It will be found simpler to compute the curves for equal steps near their intersection and interpolate. The symmetry of the curves and the intersections are independent of the amplitude of the deflections. Furthermore, the amplitude of the observed deflections should agree with the theoretical computed curves. Therefore, the agreement of the theoretical and observed curves provides a test for the adjustments of the variometers.

The double deflection-curves obtained when the magnet lies east-west are shown in Figure 11. These curves are computed from the equations (57) and (114) thus: $\tan v=(M_a/H)[(2D_D^2-a^2)/(D_D^2+a^2)^{5/2}]$ and $u'=(3M_a/s)[(D_Ha\times 10^5/(D_H^2+a^2)^{5/2}]$, the given quantities being same as for Figure 10.

49. *D- and H-deflection curves, north side*—The double deflection-curves for magnet M_a, north end north, as it is moved along the line north, N, are shown in Figure 12 ($M_a=10{,}000$, $H=0.1856$ c.g.s., $D=200$ cm, and $s=2.85$). They are computed from the equations

$$(180)\qquad \tan v=(M_a/H)[Db/(D^2+b^2)^{5/2}]\quad (D\text{-variometer})$$

$$(181)\quad u'=(M_a/s)\{[2D^2-(b-59)^2]/[D^2+(b-59)^2]\}10^5\quad (H\text{-variometer})$$

the origin being referred to the D-variometer.

The double deflection-curves on the north side, with magnet M_a east-west are shown in Figure 13 ($M_a=10{,}000$, $H=0.1856$ c.g.s., $D=200$ cm, and $s=2.85$). They are computed from the equations

$$(182)\qquad \tan v=(M_a/H)[(2b^2-D^2)/(D^2+b^2)^{5/2}]\quad (D\text{-variometer})$$

$$(183)\quad u'=(3M_a/s)\{D(b-59)/[D^2+(b-59)^2]^{5/2}\}10^5\quad (H\text{-variometer})$$

50. *Compound curves, D-variometer, north side*—From equation (22) we see that the actual deflection-curve is compounded of two characteristic types, which arise when the magnet M_a is parallel to the y-axis (east-west) or when M_a is parallel to x-axis (north-south). An interesting curve is obtained when the magnet M_a is placed at 45°. Transforming ordinates, we have for our deflection-curve (single deflections), using the characteristic curves expressed by equations (63) and (69)

$$(184)\quad u=(M_a/H\epsilon)\cdot[(D^2-2b^2)/(D^2+b^2)^{5/2}]\ \sin\ 45°-[3Db/(D^2+b^2)^{5/2}]\ \cos 45°\ =(0.707\ M_a/H\epsilon)[(D^2-2b^2-3Db]/(D^2+b^2)^{5/2}]$$

The curve is shown in Figure 14 ($M_a=10{,}000$, $H=0.1856$ c. g. s., and $D=200$ cm), where $\epsilon=1'$.

To facilitate plotting the curve, we note that the deflection is zero when

$$f = (D^2 - 2b^2 - 3Db)/(D^2+b^2)^{5/2} = 0$$

or

(185) $$2b^2 + 3Db = D^2$$

that is for $b = 0.2808D$ or $-1.7808D$. Differentiating f with respect to b, and simplifying

(186) $$\delta f/\delta b = -3[(b+2D)\ (2b^2 - 3D^2) + 5D^3]/(D^2+b^2)^{7/2}$$

whence, for maximum or minimum

(187) $$(b+2D)\ (3D^2 - 2b^2) = 5D^3$$

This can be solved by trial when $D = 200$, $b = -51.2$ for maximum and $b = 154.8$ for minimum. A point of inflection, which may be computed from

(188) $$[(b+2D)\ (3D^2 - 2b^2) + 5D^3]/(D^2+b^2)^{7/2}$$

occurs at that point which gives the maximum value of (188). We can make the deflections symmetrical by changing the deflecting-magnet to 135° at the point zero. The branch for b positive is shown by the dotted line.

51. *Compound deflection-curves, H-variometer, north side*—The compound deflection-curves for the H-variometer with the deflecting-magnet at 45°, are obtained by combining the two characteristic curves (112) and (114) into the following compound curve ($\phi = 45°$)

(189) $$u' = (0.707\ M_a/s)[(2D^2 - b^2 + 3Db)/(D^2+b^2)^{5/2}]$$

This is zero when $(b^2 - 3Db) = 2D^2$, whence $b = 3.56D$ or $-0.56D$. Differentiating, with respect to b, the function

(190) $$f = (2D^2 - b^2 + 3Db)/(D^2+b^2)^{5/2}$$

(191) $$\delta f/\delta b = 3[(b-4D)\ (b^2 - 4D^2) - 15D^3]/D^2+b^2)^{7/2}$$

For a maximum or minimum

(192) $$(b-4D)\ (b^2 - 4D^2) = 15D^3$$

For $D = 200$ cm the minimum for b is 42.0. The point of inflection is determined by the maximum value of

(193) $$[(b-4D)\ (b^2 - 4D^2) - 15D^3]/(D^2+b^2)^{7/2}$$

and is solved by trial. In the curve (189), the points of inflection occur at $b = -40$ and $+120$, approximately. The curve, shown in Figure 15, may be made symmetrical, as indicated by the dotted line, by placing the north end of the magnet $\phi = -45°$ from $-b$ to 0, and $\phi = 45°$ from 0 to $+b$.

52. *Simultaneous deflections of all three variometers*—The simultaneous deflections of D- and H-variometers may be effected from other positions, which readily suggest themselves; for example, when the deflecting-magnet M_a is level, with its center in the yz-plane, with respect to the variometers, and its axis making an angle with the x-axis. The

component $M_a \cos \alpha$ will deflect the H-variometer, while the component $M_a \sin \alpha$ will deflect the D-variometer. D and Z may also be simultaneously deflected, for example, by placing M_a vertical in the plane with reference to these variometers. Furthermore, all three variometers may be simultaneously deflected provided the deflecting-magnet M_a has both vertical and horizontal components. The most useful of these positions is that north (or south) of the Z-variometer, the center being in the xy-plane, and its axis inclined in the east-west plane, at some convenient angle. The component $M_a \sin \omega$ deflects the Z-variometer, while the component $M_a \cos \omega$ deflects the D- and H-variometers. In all these cases, the deflection-curves have the same characteristics as the types already discussed.

53. *Scale-values by deflections, D- and H-variometers*—The general equation (106) for the deflections of an H-variometer may be written

$$s=(M_a/d^3u)\ (3 \cos \delta \cos \beta \cos \alpha-\cos \omega \cos \phi)\ 10^5$$

from which it is clear the scale-value of the H-variometer may be derived from the deflection produced by any magnet whose magnetic moment is known, provided the distances and angles are also known. The magnetic moment may be determined, for example, from a magnetometer, care being taken to eliminate the effects of distribution and torsion. The magnet of the standard observatory H-variometer itself might be used as a deflector for variometer scale-values: this would have the advantage of a consistent scheme of values obtained from a standard magnet. According to the usual practice, any convenient deflecting-magnet is used, the magnetic moment of which is determined by equation (17) from the deflections of the D-variometer. When the same magnet is used for both variometers, M_a may be eliminated, and hence the general scale-value equation is

$$(194)\qquad s=(d_D^3H_\gamma \tan v/d_H^3u')[(3 \cos \delta \cos \beta \cos \alpha-\cos \omega \cos \phi)_H/(3 \cos \delta \cos \beta \sin \alpha-\cos \omega \sin \phi)_D$$

in which the subscript D refers to the D-variometer and subscript H refers to the H-variometer. In precise scale-value determinations, in comparison with other methods, and when the magnetic moment of the deflector is independently determined, allowance must be made for the fact that the value of H at the center of the D-variometer is decreased by the proximity of the Z-variometer magnet, as already mentioned in section 44.

The general scale-value equation (194) becomes much simplified when the deflections are made with the deflecting-magnet in the horizontal or xy-plane, and the same distances are used. In this case, $\omega=\beta=0°$, $\cos \delta=\cos (\alpha-\phi)$, whence

$$(195)\quad s=(H_\gamma \tan v/u')\{[3 \cos (\alpha-\phi) \cos \alpha-\cos \phi]_H/[3 \cos (\alpha-\phi) \sin \alpha-\sin \phi]_D$$

We first note the symmetrical positions, that is, where $\phi=90°$ or $0°$, and $\alpha=0°$, $45°$, or $90°$. For the A-position (corresponding to magnet east, north end east for D-variometer) we have for the D-variometer, $\alpha=\phi=90°$, and for the H-variometer $\alpha=\phi=0°$.

$$(196)\qquad s=(H_\gamma \tan v/u')$$

For the B-position, $\alpha=0°$, $\phi=90°$ for the D-variometer and $\alpha=90°$; $\phi=0°$ for the H-variometer

(197) $s=(H_\gamma \tan v/u')$ (deflections one-half A-position)

For the C-position, $\omega=\delta=0°$, $\phi=\beta=90°$ for the D-variometer, and $\omega=\phi=0°$, $\delta=\beta=90°$ for the H-variometer, and from (194)

(198) $s=(H_\gamma \tan v/u')$ (deflections, one-half A-position)

For the D-position, $\alpha=45°$, $\phi=0°$, for the D-variometer, and $\alpha=45°$, $\phi=90°$ for the H-variometer, and from (195)

(199) $s=(H_\gamma \tan v/u')$ (deflections, three-fourths of A-position)

Any combination of these positions can be used with equation (194). For example: B-position for D, $\alpha=0°$, $\phi=90°$, and A-position for H, $\alpha=\phi-0°$

(200) $$s=(H_\gamma \tan v/u')\ (2)$$

A-position for D, $\alpha=\phi=90°$, B-position for H, $\alpha=90°$, $\phi=0°$

(201) $$s=(H_\gamma \tan v/u')\ (1/2)$$

D-position for D, $\alpha=45°$, $\phi=0°$, A-position for H, $\alpha=\phi=0°$

(202) $$s=(H_\gamma \tan v/u')\ (4/3)$$

B-position for D, $\alpha=0°$, $\phi=90°$, D-position for H, $\alpha=45°$, $\phi=90°$

(203) $$s=(H_\gamma \tan v/u')\ (3/2)$$

Expanding equation (195), we obtain

(204) $$s=(H_\gamma \tan v/u')\,[3 \sin\alpha \cos\alpha \sin\phi+(3\cos^2\alpha-1)\cos\phi]_H/[(3\sin^2\alpha-1)\sin\phi+3\sin\alpha\cos\alpha\cos\phi]_D$$

When $\phi=90°$ for D and $\phi=0°$ for H

(205) $$s=(H_\gamma \tan v/u')[(3\cos^2\alpha-1)_H/(3\sin^2\alpha-1)_D]$$

When $\phi=0°$ for D and $\phi=90°$ for H

(206) $$s=(H_\gamma \tan v/u')[(3\sin\alpha\cos\alpha)_H/(3\sin\alpha\cos\alpha)_D]$$

When $\phi=0°$ for D and $\phi=0°$ for H

(207) $$s=(H_\gamma \tan v/u')[(3\cos^2\alpha-1)_H/(3\sin\alpha\cos\alpha)_D]$$

When $\phi=90°$ for H and D

(208) $$s=(H_\gamma \tan v/u')[(3\sin\alpha\cos\alpha)_H/(3\sin^2\alpha-1)_D]$$

In equations (204) to (208), the distances are the same for both variometers. Hence as the deflecting-magnet is rotated by steps with a bar (say) a series of scale-values may be obtained. The angle α may be the same or different, or conveniently chosen for the purpose in hand.

When the distances are not the same for both variometers, we derive for the xy-plane, from equation (194)

(209) $$s=(d_D^3\, H_\gamma \tan v/d_H^3\, u')\{[3\sin\alpha\cos\alpha\sin\phi+(3\cos^2\alpha-1)\cos\phi]_H/[(3\sin^2\alpha-1)\sin\phi+3\sin\alpha\cos\alpha\cos\phi]_D$$

Introducing the relations $\sin \alpha = b/d$, $\cos a = a/d$

(210) $(s = (d_D{}^3\, H_\gamma \tan v/d_H{}^3\, u')\,[3\,ab \sin \phi + (2a^2 - b^2)\cos \phi]_H/[(2b^2 - a^2)$
$\sin \phi + 3ab \cos \phi]_D$

When the deflecting-magnet moves along a line west in our magnetograph with north end north, $\phi = 0°$ for both D- and H-variometers, $b = D_D$ for the D-variometer, and $b = D_H$ for the H-variometer. We have $d_D{}^2 = D_D{}^2 + a_D{}^2$ and $d_H{}^2 = D_H{}^2 + a_H{}^2$. From (210)

(211) $s = (H_\gamma \tan v/u')\;[(D_D{}^2 + a_D{}^2)/(D_H{}^2 + a_H{}^2)]^{5/2}[(2a_H{}^2 - D_H{}^2)/3D_D a_D]$
(line west)

When $\phi = 90°$, we get

(212) $s = (H_\gamma \tan v/u')[(D_D{}^2 + a_D{}^2)/(D_H{}^2 + a_H{}^2)]^{5/2}[3D_H a_H/(2D_D{}^2 - a^2{}_D)]$
(line north)

When the deflecting-magnet moves along line north, $D = a$ for both variometers. Hence, when $\phi = 0°$

(213) $s = (H_\gamma \tan v/u')[(D^2 + b_D{}^2)/(D^2 + b_H{}^2)]^{5/2}[(2D^2 - b_H{}^2)/3Db_H]$
(line north)

When $\phi = 90°$

(214) $s = (H_\gamma \tan v/u')[(D^2 + b_D{}^2)/(D^2 + b_H{}^2)]^{5/2}[3Db_H/(2b_D{}^2 - D^2)]$
(line north)

The subscripts indicate the coordinates of the respective D- and H-variometers. For scale-value determinations from deflections along the lines west and north we are not limited to points having the same coordinates a and b. Naturally we would select the points having a sufficient deflection. Furthermore, we may determine the scale-values from a deflection or series of deflections along line west for one variometer, and from points on line north for the other variometer. For example, deflecting H from line west with axis of M_a north $(\phi = 0°)$, and deflecting the D-variometer from line north $(\phi = 0°)$

(215) $s = (H_\gamma \tan v/u')[(D_N + b_D{}^2)/(D_{HN}{}^2 + a_H{}^2)]\;[(2a_H{}^2 - D_H{}^2)/(2b_D{}^2 -$
$D_D{}^2)]$

54. *Scale-values of H-variometer, magnet inclined or tilted*—Still other forms of the scale-value equation may be obtained, according as the axis of the deflecting-magnet M_a is level ($\omega = 0°$) and inclined at an angle, or as the axis of M_a is tilted in a vertical plane perpendicular or parallel to the line d. Thus in equation (195) we may have $\alpha = 0°$ for the D-variometer, and $\alpha = 90°$ for the H-variometer. Hence for axis inclined

(216) $s = (H_\gamma \tan v/u')[(\cos \phi)_H/(\sin \phi)_D] = H_\gamma \tan v/u'$ (B-position)

since $\sin \phi$ referred to the position of M_a when deflecting the D-variometer is the same as $\cos \phi$ when deflecting the H-variometer. If $\alpha = 90°$ for D, and $\alpha = 0°$ for H

(217) $s = (H_\gamma \tan v/u')[(2 \cos \phi)_H/(2 \sin \phi)_D] = H_\gamma \tan v/u'$ (A-position)

If $\omega = 0°$, $\beta = 90°$, $\delta = 90°$ for both variometers, from (194), the distances being the same

(218) $s = (H_\gamma \tan v/u')[(\cos \phi)_H/(\sin \phi)_D] = H_\gamma \tan v/u'$ (C-position)

When the axis of M_a is tilted to the horizontal plane, distances being the same, if $\beta=0°$, $\alpha=\phi=90°$, $\cos\ \delta=\cos\ \omega$ for the *D*-variometer, and $\alpha=\phi=\beta=0°$, $\cos\ \delta=\cos\ \omega$ for the *H*-variometer, we have from (194)

(219) $s=(H_\gamma \tan v/u')[(2\cos\ \omega)_H/(2\cos\ \omega)_D]=H_\gamma \tan v/u'$ (*A*-position)

If $\alpha=\beta=0°$, $\delta=\phi=90°$ for the *D*-variometer, and $\alpha=\delta=90°$, $\phi=0°$ for the *H*-variometer

(220) $s=(H_\gamma \tan\ v/u')[(\cos\ \omega)_H/(\cos\ \omega)_D]=H_\gamma \tan\ v/u'$ (*B*-position)

If $\alpha=\phi=\beta=90°$, $\cos\ \delta=\sin\ \omega$ for the *D*-variometer, and $\alpha=\phi=0°$, $\beta=90°$, $\cos\ \delta=\sin\ \omega$ for the *H*-variometer

(221) $s=(H_\gamma \tan\ v/u')[(\cos\ \omega)_H/(\cos\ \omega)_D]=H_\gamma \tan\ v/u'$ (*C*-position)

The most convenient angles are $\phi=45°$ and $\omega=45°$ for both variometers. In general, for the same distances, when the deflecting-magnet has the same relative position with respect to both *D*- and *H*-variometers, the factor in (194) and (195) containing the angles cancels out.

55. *Scale-values, D- and H-variometers, simultaneous deflections*—An inspection of the deflection-curves and the scale-value equations so far derived suggests that scale-values may be determined by deflecting both *D*- and *H*-variometers at the same time, assuming the deflections are large enough for the purpose. Where the curves change rapidly, increased accuracy may be obtained by deflecting at two near-by points equidistant from the point selected; the mean of the deflections at the near-by points should agree with those at the selected point. The scale-value equations have been given in the preceding sections.

56. *Scale-values, Z-variometer*—The scale-value of the *Z*-variometer is usually obtained from deflections of the *D*- and *Z*-variometers. From equation (159) we have

$$s=M_a/d^3u'=(3\cos\ \delta\sin\ \beta-\sin\ \omega)10^5$$

Thus, as in the case of the *H*-variometer, any deflecting-magnet may be used whose magnetic moment is known. We are, of course, assuming that the deflecting-magnet is far enough away to eliminate distribution-effects. The magnetic moment of M_a is, from the *D*-deflection equation (17)

(222) $M_a=d^3H_\gamma \tan\ v\times10^{-5}/(3\cos\ \beta\cos\ \delta\sin\ \alpha-\cos\ \omega\sin\ \phi)$

Thus for the general scale-value equation for the *Z*-variometer, using an appropriate subscript-notation, we obtain

(223) $s=(d_D^3/d_Z^3)\ (H_\gamma \tan\ v/u')[(3\cos\ \delta\sin\ \beta-\sin\ \omega)_Z/(3\cos\ \beta\cos\ \delta\ \sin\ \alpha-\cos\ \omega\sin\ \phi)_D]$

For the *A*-position referred to the *D*-variometer, $\beta=\omega=0°$, $\alpha=\phi=90°$, $\cos\ \delta=\cos\ (\alpha-\phi)=1$. For the corresponding position referred to the *Z*-variometer, $\omega=\beta=90°$, $\cos\ \delta=1$; also $d_D=d_Z$. Hence

(224) $s=(H_\gamma \tan\ v/u')$ (*A*-position)

In the *B*-position, we have for the *D*-variometer, $\alpha=\beta=\omega=0°$, $\phi=90°$, and for the *Z*-variometer, $\alpha=\beta=0°$, $\omega=90°$. Hence

(225) $s=(H_\gamma \tan\ v/u')$ (deflections one-half *A*-position)

In the C-position, for the D-variometer, $\beta=\phi=90°$, $\omega=0°$. For the Z-variometer, $\beta=0°$, $\alpha=\phi=90°$.

(226) $s=(H_\gamma \tan v/u')$ (deflections one-half A-position)

If different distances are used, the fraction $d_D{}^3/d_Z{}^3$ will be retained in the equations.

As in the case of the H-variometer, scale-value equations could be derived for positions as the deflecting-magnet moves along a horizontal line in the meridian above the variometer and also along a vertical line in the meridian north or south of the variometer. Simultaneous deflections may be made by placing the deflecting-magnet vertical, or level in the yz-plane, east or west of the variometer, and with center above or below the horizontal plane. When the magnet is vertical, we have for the D-variometer, $\alpha=\omega=\phi=90°$, $\delta=0°$. For the Z-variometer, $\alpha=\omega=90°$, $\cos\delta=\sin\beta$. Equation (223) then becomes

(227) $s=(d_D{}^3/d_Z{}^3)\ (H_\gamma \tan v/u')[(3\sin^2\beta-1)_Z/(3\sin\alpha\cos\beta)_D]$

Using the relations, $d^2=D^2+c^2$, $D=b$, $\sin\beta=c/d$, $\cos\beta=b/d$ for the D-variometer, and a like set of relations for the Z-variometer, (227) is transformed into

(228) $s=(H_\gamma \tan v/u')[(D^2+c^2)_D{}^{5/2}/(D^2+c^2)_Z{}^{5/2}]\ [(2c^2-D^2)_D/(3Dc)_D]$
(simultaneous D- and H-magnet vertical in yz-plane)

When the deflecting-magnet is horizontal, we have for the D-variometer $\alpha=\phi=90°$, $\omega=0°$, $\cos\delta=\cos\beta$, and for the Z-variometer, $\alpha=\phi=90°$, $\omega=0°$, $\cos\delta=\cos\beta$. Equation (223) then becomes

(229) $s=(d_D{}^3/d_Z{}^3)\ (H_\gamma \tan v/u')[(3\cos\beta\sin\beta)_Z/(3\cos^2\beta-1)_D]$

Using the relations, $D=c$, $d^2=D^2+b^2$, $\sin\beta=c/d$, $\cos\beta=b/d$, (229) is transformed into

(230) $s=(H_\gamma \tan v/u')[(D^2+b^2)_D/(D^2+b^2)_Z]^{5/2}[(3Db)_Z/(2b^2-D^2)_D]$
(simultaneous D- and H-magnet horizontal in yz-plane)

57. *H- and Z-scale-values from simultaneous deflections of all three variometers*—We have seen how, in a magnetograph, the D- and H-variometers may be simultaneously deflected when the deflecting-magnet is placed on line north. If the deflecting-magnet is inclined to the xy-plane, the vertical component $M_a \sin\omega_0$ will deflect the Z-variometer, while the horizontal component will deflect both D and H. The largest deflections on all three variometers will be obtained when the deflecting-magnet is placed north of D and Z, with its axis inclined in the vertical east-west plane. The component deflecting Z is $M_s \sin\omega_0$ and the horizontal component is $M_s \cos\omega_0$. We have the following conditions for the variometers, assuming the Z-magnet to be above the xy-plane, coordinate $=-c$: D-variometer—$\phi=90°$, $\beta=\omega=0°$, $\cos\delta=\sin\alpha$, $D=a_D$; H-variometer—$\phi=90°$, $\beta=\omega=0°$, $\cos\delta=\sin\alpha$, $D=a_H$; Z-variometer—$\alpha=0°$, $\phi=\omega=90°$, $\cos\delta=\sin\beta$, $D=a_Z$. Since we are assuming that equal magnetic moments are deflecting the D- and Z-variometers, $\omega_0=45°$, otherwise it would be necessary to determine the magnetic moment of M from the D-deflections, and use the value $M\sin\omega_0$ for M_a in equation (159). Substituting the above conditions in equation (223) we obtain for the Z-scale-value

(231) $s_Z=(d_D{}^3/d_Z{}^3)\ (H_\gamma \tan v/u_Z')[(3\sin^2\beta-1)_Z/(3\sin^2\alpha-1)_D]$

Transforming by the relations $\sin\beta=-c/d$, $\cos\beta=a/d$, $d_Z{}^2=D^2+c_Z{}^2$, $\sin\alpha=b/d$, $\cos\alpha=a/d$, $d_D{}^2=D^2+b_D{}^2$, we obtain

(232) $s_Z=(H_\gamma\ \tan v/u')[(D^2+b^2)_D/(D^2+c^2)_Z]^{5/2}[(2c^2-D^2)_Z/(2b^2-D^2)d]$

The H-scale-value has already been derived in equation (214), § 53.

In the use of a magnet for testing purposes, the magnetic moment of the deflector will usually be determined from the D-variometer, a correction being made for the change in H due to the proximity of the Z-magnet (Eschenhagen type of magnetograph) and to the proximity of other magnets, if necessary. The most favorable position for determining the magnetic moment is the A-position, where the deflections are greatest and where the errors of setting are least, as discussed in § 13. If, however, the magnetic moment is determined from a magnetometer, the effects of distribution and torsion should be allowed for. For testing the D- and H-variometers, the simplest of deflections are obtained from lines parallel and perpendicular to the magnetic meridian, and from vertical lines. The deflections will show errors of orientation and of heights of the variometer-magnets, and should show a consistent series of scale-values. The Z-variometer may be tested in a similar way. The adjustment of the magnetograph, from the standpoint of the deflections of the magnets themselves, may be considered as satisfactory when there is complete agreement between theory and experiment.

United States Coast and Geodetic Survey,
Washington, D. C

NOTES

(See also pages 56 and 62)

8. *Investigation of cosmic rays*—During the spring and summer of 1932 more than a dozen physicists, working in several parties under the direction of Dr. Arthur H. Compton, of the University of Chicago, will test the intensity of the cosmic rays at thirteen sites. Electrometer readings, to be taken largely in mountain ranges, will be made in Panama, Peru, New Zealand, Australia, Hawaii, Alaska, Argentine, Chile, Kashmir, Ceylon, Singapore, Java, and South Africa. The expense of these expeditions will be shared by the Carnegie Corporation and the University of Chicago. These investigations are in continuance of the work carried on last fall on Mount Evans, Colorado (see this Journal, **36**, 242, 1931), and on the Jungfrau in the Swiss Alps. The projected measurements will be made at widely distributed stations and at different altitudes on mountains ranging in height from 7,000 to 20,000 feet or more. The objective of the expeditions as set forth by Dr. Compton is "more complete knowledge of the nature and place of origin of the cosmic rays. A survey such as this should give the most adequate test that has yet been devised to distinguish whether cosmic rays are photons, such as light and x-rays are, or electrons, such as give rays to the Earth's aurora." The grant from the Carnegie Corporation was made through the Carnegie Institution of Washington.

9. *Geophysical Lectures at the Carnegie Institution of Washington*—A series of three lectures pertaining to the magnetic field of the Earth and its atmosphere were given on the evenings of March 8, 15, and 22, 1932, under the auspices of the Carnegie Institution of Washington at its Administrative Building in Washington. These lectures were as follows: Time changes of the Earth's magnetic field, by J. A. Fleming, acting director, Department of Terrestrial Magnetism; Cosmic disturbances of the Earth's magnetic field and their influences upon radio communication, by A. E. Kennelly, professor emeritus of electrical engineering, Harvard University and Massachusetts Institute of Technology; Tides in the atmosphere, by J. Bartels, professor of meteorology, Forstliche Hochschule, Eberswalde, Germany. Messrs. Kennelly and Bartels are also research associates of the Carnegie Institution of Washington.

10. *American office of R. Fuess*—The house of Rudolf Fuess, manufacturers of scientific instruments, with works at Berlin-Steglitz, has announced the establishment of an American office under the name of R. Fuess, Inc., located at 245 West 55th Street, New York, N. Y.

11. *Errata*—The following corrections are to be made in the article by C. E. Deppermann, S.J., in the September 1931 number of the JOURNAL: For "southeast" in the first line on page 237 read "southwest"; for "since days in which no negative potential occurs are exceedingly rare" in the fourth line from the bottom of the page read "since days in which negative potential occurs are very infrequent."

Through an unfortunate disarrangement of the cuts on pages 350, 351, and 352 of the December 1931 number of the JOURNAL in the article by Gustaf S. Ljungdahl the title on page 350 should be under the figure shown on page 351, that on page 351 should be under the figure shown on page 352, and that on page 352 should be under the figure shown on page 350.

12. *Personalia*—Dr. *Adolf Schmidt*, formerly director of the Meteorological-Magnetic Observatory, and after whom the new magnetic observatory at Niemegk has been named, celebrated the fiftieth anniversary of his doctorate on March 20.

Sir *Arthur Schuster* has been awarded the Copley Medal of the Royal Society of London, for his fundamental researches in various branches of physical science, including his important contributions to terrestrial magnetism.

Prof. *J. C. McLennan* has resigned his position as dean of the School of Graduate Studies, professor of physics, and director of the Physical Laboratory, at the University of Toronto, to take effect at the end of June 1932. He was granted leave of absence from the end of January, and he and Mrs. McLennan left at that time for England, where they intend to make their home.

Prof. *Luigi Palazzo* retired, on November 1, 1931, from the directorship of the R. Ufficio Centrale di Meteorologia e Geofisica of Rome—a post which he has held for the past 30 years. During this period he devoted much time to the study of terrestrial magnetism, giving especial attention to magnetic survey-work in Italy and in the Italian colonies in Africa. He also took an active part in the meetings of the International Union of Geodesy and Geophysics and for several years was vice-president of its Section of Terrestrial Magnetism and Electricity. He is succeeded in the directorship of the R. Ufficio Centrale di Meteorologia e Geofisica by his distinguished colleague, Prof. *Emilio Oddone*, who is widely known for his seismological researches.

Dr. *Warren Weaver*, formerly professor of mathematics at the University of Wisconsin, has been appointed director of the Natural Sciences of the Rockefeller Foundation, New York City.

Dr. *Hugo Eckener*, president of Aeroarctic and commander of the airship Graf Zeppelin, received on January 16, 1932, the award of the 1931 medal of the International Aeronautic Federation.

Dr. *J. Bartels*, who, as a research associate of the Carnegie Institution of Washington, has been engaged on the theoretical interpretation of the accumulated observational data at the Department of Terrestrial Magnetism in Washington, D. C., having completed this year's leave of absence from Germany, has returned to his position in the Forstliche Hochschule in Eberswalde.

Father *Louis Froc*, S. J., retired at the end of August 1931 from the post of director of the Zi-ka-wei Observatory, Shanghai, which he had held since 1896.

Andrew Thomson, previously aerologist for the Meteorological Service of New Zealand and for some years director of the Apia Observatory, Western Samoa, has been appointed meteorologist in the Canadian Meteorological Service.

Prof. *S. Chapman*, chief professor of mathematics, Imperial College of Science and Technology, London, has been elected president of the Royal Meteorological Society for the year 1932.

We regret to record the death, on February 16, 1932, of General *Gustave Ferrié*, first vice-president of the International Council of Scientific Unions and president of the Section of Terrestrial Magnetism and Electricity of the French National Committee. General Ferrié enjoyed an international reputation for his work in scientific radiotelegraphy and was president of the International Union for the investigation of that subject. He was in his 64th year at the time of his death.

We regret to record also the death, on February 18, of Dr. *D. W. Dye*, principal assistant in the Electrical Standards Department of the National Physical Laboratory, aged 44 years. He is known to readers of the JOURNAL for his work on absolute magnetic instruments of high precision of the Schuster-Smith type.

THE AGINCOURT SCHUSTER-SMITH COIL-MAGNETOMETER

By W. E. W. Jackson

In August 1931 a Schuster-Smith coil-magnetometer was installed in the Magnetic Observatory at Agincourt, and is now being used as the standard for horizontal-force determinations.

It may be of interest to other observatories to know how it has functioned during the several months it has now been in operation, and also the results obtained in a series of intercomparisons with our Elliott Magnetometer No. 98, which was in use formerly as the standard, and whose correction on the Department of Terrestrial Magnetism provisional International Magnetic Standard, had been obtained through intercomparison with DTM CIW Instrument No. 15, which was standardized at Washington, D. C., U. S. A.

A full description of the first Schuster-Smith coil-magnetometer is to be found in the Philosophical Transactions of the Royal Society (**223**, pp. 175-200). A short account is given in the Dictionary of Applied Physics (**2**, 529-532). The principle of the instrument was first described by Sir Arthur Schuster[1] and is briefly as follows.

A horizontal magnetic field whose intensity is slightly greater than that of the Earth is imposed at an angle of nearly 180° with the Earth's field. A small magnet suspended therein takes up a position as a result of the two forces at right-angles to the Earth's field. By slight adjustment of the coil controlling the imposed field the magnet can be made to lie in a position exactly 90° to the Earth's field and the angle of displacement of the coil from the magnetic meridian is then read off an azimuth-circle. A simple relation now exists between the imposed field and that of the Earth expressed by the equation $H = Fi \cos \alpha$, where H is the Earth's field, F the constant of the coil, i the current, and α the angle through which the coil has been turned.

F, the constant of the coil, was determined by intercomparison with the first instrument of its kind at the Abinger Observatory and is 0.360049 $[1-(1.8T\times10^{-6})]$ where T is the temperature in degrees centigrade.

The current is supplied by a battery of 48 cells giving a voltage of about 100 and is controlled by a rheostat with adjustable resistance of 4 dial switches having ten steps in each of (*a*) 20, (*b*) 2, (*c*) 0.2, and (*d*) 0.02 ohms per step, and in addition a continuous variable mercury resistance of 0.022 ohm, and a permanent resistance of 47 ohms.

At Agincourt the current required to produce the necessary field is about 0.43 ampere and its value is determined accurately by balance against a Weston standard cell through a potentiometer with a Broco galvanometer as indicator. The Weston cell and potentiometer were standardized at the National Physical Laboratory and the constants were supplied for various standard temperatures. The potentiometer has two coils with fixed resistance of approximately one international ohm each, one of which can be short-circuited if required, and 3 dial-switches having ten steps each of approximately 0.1, 0.01 and 0.001 ohm respectively. The N. P. L. certificate gives the resistance to the fifth place of decimals for various standard temperatures.

[1] Terr. Mag., **19**, 19-22 (1914).

The observation proceeds as follows: The torsion of the suspension-thread is first eliminated by substituting a copper piece for the magnet. The magnet is then replaced and allowed to swing free in the Earth's field. The position of the light reflected by the mirror-magnet on the appropriate scale is noted. This scale is normally on the west side of

AGINCOURT OBSERVATORY August 12, 1931

LATITUDE 43° 47′ N. LONGITUDE 79° 16′ W

ABSOLUTE HORIZONTAL FORCE—SCHUSTER SMITH COIL MAGNETOMETER

75th M T	H Variometer	COIL MIRROR North: Magnet Mirror	Verniers	Coil T	Mean Verniers	POTENTIOMETER R	POTENTIOMETER T	Cell T
h m			° ′ ″	°	° ′ ″		°	°
		W	A 17 21 40					
			B 197 21 50		17 21 45			
			A 15 18 20	21.4				
12 46	161.80	N	B 195 18 30	21.4	15 18 25	2.362	21.3	21.2
			A 19 28 20	21.5				
53	161.50	S	B 199 28 40	21.5	19 28 30	2.362	21.4	21.4

$H = Fi\left(\frac{\cos\alpha + \cos\beta}{2}\right)$ $\alpha = 2°\ 03'\ 20''$ $\cos\alpha = 0.999356$

$i = \frac{E}{R}$ $\beta = 2\ 06\ 45$ $\cos\beta = 0.999320$

$\frac{\cos\alpha + \cos\beta}{2} = 0.999338$

Log E.M.F	= 0.007 833	R = 2.362
Reduction for T	= −0.000 024	corrected for T 21°.3
Log E	= 0.007 809	0.999 93
Log R	= 0.373 271	1.000 00
Log i (Int.)	= 9.634538	0.300 02
Reduction to C.G.S.	= 9.999 987	0.06000
Log i	= 9.634525	0.00200
Log F	= 9.556346	R = 2.36195
Log $\frac{\cos\alpha + \cos\beta}{2}$	= 9.999 712	
Log H	= 9.190583	
H	= 0.155090	Mean H Variometer = 161.65
Reduction to Base	= 0.000864	H Variometer Base = 180
H Base	= 0.155954	

Remarks— very steady Observers— Jackson and Ross

FIG. 1—Specimen observation and computation

the instrument. By optical methods reference marks on two other scales placed respectively magnetic north and magnetic south are adjusted accurately to points 90° from the magnet-mirror spot. The current is then passed around the coils in a direction to produce a field acting in the same direction as the Earth's field and the coil is turned in azimuth until the addition of the imposed field produces no alteration in the direction of the magnet. The coil is then accurately parallel to the Earth's field and its position is read on the azimuth-circle.

The current is now reversed in the coil by a commutator-switch, the magnet-box is turned through 90°, carrying the magnet with it, and the coil adjusted in azimuth until the magnet is at 90° with the Earth's field as shown by the spot of light reflected by the magnet-mirror on the north scale position-line. The azimuth-circle is then read, giving the angle α by which the coil has been turned from its position of parallelism with the Earth's field. The magnet-box is then turned through 180° and the coil shifted to the other side of the meridian and again adjusted to bring the magnet at right-angles to the meridian, this time by the light reflected to the south scale. Again the azimuth is read, and a second angle B is obtained.

Throughout these observations the current is kept at a steady fixed value by a second observer, who adjusts the variable resistance of the rheostat, if necessary, according to the indications of the galvanometer.

Eye-readings are made of the differential horizontal force magnetometer simultaneous with each setting of the coil and from these the values of the base-line of the photographic records are obtained.

The form, shown in Figure 1, is used in making and reducing the observations.

The following table gives the results of observations made on August 12, 1931, and the results of comparison with the magnetograph, the values of which are deduced from observations with magnetometer 98 reduced to the International Magnetic Standard of the Department of Terrestrial Magnetism of the Carnegie Institution.

75° west mean time		Current i	Angles α			Angles β			$\log\left(\frac{\cos\alpha+\cos\beta}{2}\right) = \log a$	(1) $H = Fi \times a$	(2) I.M.S. H magnetogr. and mag'r Elliott 98	Diff. [(1)−(2)]
h	*m*	*cgs*	°	′	″	°	′	″		*cgs*	*cgs*	γ
10	17	.431827	4	17	40	4	19	45	0.997170	.155034	.155016	−1.8
10	28	.431825	4	23	40	4	20	40	0.997094	.155021	.155015	−0.6
10	39	.431818	4	10	10	4	12	20	0.997330	.155050	.155039	−1.1
10	50	.431817	4	5	15	4	10	0	0.997406	.155067	.155048	−1.9
11	2	.430896	2	4	0	2	18	5	0.999272	.155025	.155006	−1.9
11	22	.430890	2	40	40	2	16	5	0.999062	.154990	.154978	−1.2
11	34	.430701	1	9	55	0	54	5	0.999834	.155042	.155025	−1.7
11	50	.430696	1	4	0	1	16	50	0.999788	.155033	.155005	−2.8
12	50	.431047	2	3	20	2	6	45	0.999338	.155090	.155066	−2.4
13	4	.431045	2	11	50	1	57	15	0.999341	.155089	.155053	−3.6
13	10	.431036	1	57	25	1	55	20	0.999428	.155099	.155072	−2.7
13	16	.431034	1	53	0	1	37	15	0.999530	.155125	.155073	−5.2
											Mean	−2.2
											P.E. mean	±0 02

It should be noted that the value of the current was intentionally altered so as to vary the values of i, α, and β. The coil was also alternately swung through 180° and the current reversed to give the proper direction of the imposed field.

The value of the photographic base has been determined by this method from the middle of August 1931 to the end of December. Two observations a week were made with temperatures varying from 23°C to 5°C with the following results:

Date	75° west mean time		Magnetograph	Coil temp.	Magnetograph base
1931	*h*	*m*		° *C*	*cgs*
Aug. 17	9	32	161.70	21.3	.155938
17	9	42	161.58	21.4	.155944
25	9	18	154.48	20.0	.155919
25	9	29	154.50	20.1	.155931
31	9	40	159.68	14.6	.155900
31	9	46	159.68	14.7	.155906
Sep. 8	9	24	161.80	16.3	.155939
8	9	32	161.42	16.4	.155943
8	9	47	160.58	16.6	.155932
8	9	54	161.02	16.7	.155940
15	11	50	154.18	22.4	.155986
15	12	00	154.22	22.4	.155983
22	10	18	160.55	22.6	.155973
22	10	24	160.30	22.7	.155980
29	10	20	158.52	14.0	.155924
29	10	26	158.45	14.1	.155923
Oct. 6	10	28	156.58	15.4	.155923
6	10	36	156.55	15.4	.155918
13	10	39	153.98	10.4	.155944
13	10	48	153.70	10.5	.155911
20	12	52	161.25	13.3	.155945
20	13	4	161.55	13.6	.155962
27	10	30	154.65	13.4	.155990
27	10	38	154.32	13.4	.155986
Nov. 3	10	42	159.25	14.6	.155956
3	10	50	159.12	14.7	.155975
10	10	34	153.08	17.0	.155918
10	10	40	153.35	17.0	.155936
17	10	42	157.58	17.2	.155979
17	10	50	157.70	17.2	.155971
24	10	28	160.18	19.3	.155979
24	10	36	160.15	19.3	.155984
Dec. 1	10	36	155.48	14.4	.155951
1	10	43	156.65	14.5	.155958
8	10	39	160.30	5.5	.155907
8	10	48	159.98	5.2	.155908
15	12	58	158.98	12.2	.155949
15	13	8	159.08	12.3	.155936
15	13	24	158.70	12.4	.155947
23	11	22	155.48	14.0	.155963
23	11	29	155.62	14.0	.155958
29	14	5	159.00	11.7	.155947
29	14	14	159.55	11.8	.155935

Meteorological Service of Canada,
Toronto, Canada

LETTERS TO EDITOR

PROVISIONAL SOLAR AND MAGNETIC CHARACTER-FIGURES, MOUNT WILSON OBSERVATORY, OCTOBER, NOVEMBER, AND DECEMBER, 1931[1]

In addition to the following magnetic storms, in which the total range in *H* exceeded 100γ, three storms of slightly less intensity were recorded on November 8, 15, and 26, respectively.

Greenwich mean time						Range
Beginning			Ending			Hor. int.
1931	*h*	*m*	*d*	*h*	*m*	γ
Oct. 4	0	..	6	4	..	102
Oct. 12	14	..	13	9	..	113
Oct. 29	8	41	30	23	..	154
Dec. 2	8	..	6	0	..	111

During the storm from October 4-6 two sunspot-groups were near the central meridian, but no special activity was observed in either of them. Three very small areas of bright hydrogen within 25° of the center of the solar disk were active at the time of the magnetic storm of October 12-13. Two of these bright areas were near small spots but the third was not associated with any group. The most intense storm of the quarter, that of October 29-31, was probably due to activity associated with an average-sized group which was more than 50° west of the central meridian at the beginning of the storm.

On November 4, at 6^h 29^m, G. M. T., the horizontal intensity suddenly increased 97γ and returned in an hour to nearly its normal value. (In the Science Service Research Announcement No. 87 Tucson gives the time of beginning of the "bay" on November 4 at 6^h 35^m, whereas we recorded it at 6^h 29^m. This is the largest time-difference that we have noticed between observations here and at Tucson. Most of the comparisons have been made, however, with the times of sudden commencements.) The beginning of the moderate storm of November 8 was characterized by a similar increase in *H* at 4^h 55^m, G. M. T. An active group which crossed the central meridian on November 7.5 probably caused this storm.

The large active group which crossed the central meridian on November 26.9, G. M. T., probably caused the storm which began on that date. This group was on the west limb when the storm of December 2 began. No exceptional activity was observed in this group later than November 30.

[1] For previous tabulations from November 1929, see Terr. Mag., **35**, 47-49, 92, and 249-251 (1930), and **36**, 55-56, 142-143, and 356-357 (1931).

Day	October 1931 K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	....	....	....	....	....	....	....	1.0
2	1	2	1	2	1	1	2	1.0
3	1	2	1	2	1	1	2	1.0
4	1	2	1	2	2	0	2[g]	1.0
5	1	2	1	2	2	1	2	1.5
6	1	0.5	1	0	2	1	2	0.5
7	1	0	1	0	2	1	1	0
8	....	....	....	....	....	....	....	0.5
9	....	....	....	....	....	....	....	0
10	1	1	1	1	1	1	1	0
11	1	1	1	1	1	1	1	0
12	1	1	1	1	1	0	1	1.0
13	1	0.5	1	1	1	0	1	1.5
14	1	0	0.5	0	2	0	1	0.5
15	....	....	0	0	1	0	1	0.5
16	0	0	0	0	1	0	1	0
17	0	0	0	0	2	0	0	0.5
18	....	....	....	....	....	....	....	0.5
19	0	0	0	0	0	0	1	0.5
20	0	0	0	0	1	0	1	0.5
21	0.5	0	0.5	0	1	1	1	0.5
22	0.5	0	0.5	0	1	0	1	0.5
23	1	0	1	0	1	1	3	0.5
24	1	1	1	1	1	1	2	0.5
25	....	....	....	....	....	....	2	0
26	1	1	1	1	1	1	1	0
27	1	0	1	0	1	1	1	0.5
28	1	0	1	0	1	1	1	1.0
29	1	0	1	0	1	0	2	2.0
30	1	0	1	0	1	0.5	2	2.0
31	1	0.5	1	0.5	1	2	2	1.0
Mean	0.8	0.6	0.8	0.6	1.2	0.6	1.4	0.7

Day	November 1931 K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	0	0.5	0	0.5	2	3	1	0
2	0	0.5	0.5	0.5	2	0	2	0.5
3	0.5	0.5	0.5	0.5	1.5	0	2	0.5
4	0.5	0	0.5	0	1	0	2	1.0
5	1	1	1[a]	1[a]	1	0	2	0.5
6	....	....	1	1	1	0	2	1.0
7	....	....	....	....	....	....	..[e]	0.5
8	0.5	1	0.5	1	0.5	0	2	1.5
9	1	1	0.5	0.5	0.5	0.5	3	1.0
10	....	....	....	....	....	....	....	1.0
11	....	....	....	....	....	....	1	0
12	0	0	0.5	0	1	1	0	0
13	0	0	0	0	1	0	0	0
14	0	0	0	0	1	0	0	0.5
15	....	....	....	....	....	....	....	1.0
16	....	....	....	....	....	....	1	1.0
17	0.5	0.5	1	1	1	0.5	2	1.0
18	1	0	1	0	1	0	2	0.5
19	1	0	1	0	1	0.5	2	1.0
20	1	1	1	1	0	0	2	0.5
21	1	1	1	1	0	0	3	0
22	1	1	1.5	2	1	1.5	3	0
23	2	1.5	2.5[b]	2	1	1	4	0
24	....	....	....	....	....	....	2	0
25	1.5	2	2	2	1	1.5	2	0
26	....	....	....	....	....	....	..[f]	1.0
27	....	....	....	....	....	....	....	1.0
28	2	2.5	2	2.5	0.5	0	2	0
29	2	2	2	2	2	2	2	0
30	2	1	2[c]	1	2	1.5	2	0
Mean	0.9	0.8	1.0	0.9	1.0	0.6	1.8	0.5

Day	December 1931 K_2 A	K_2 B	$H\alpha B$ A	$H\alpha B$ B	$H\alpha D$ A	$H\alpha D$ B	No. groups	Mag'c char.
1	1	0.5	1	0.5	1	1	2	0
2	1	1	....	....	....	....	2	1.5
3	1	1	1	1.5	1	2	1	1.0
4	0.5	1	0.5	1	0.5	0	0	1.0
5	0.5	0.5	0.5	1	0.5	1	0	1.0
6	1	0	1	0	0.5	0.5	1	0.5
7	1	0	1	0.5	0.5	0.5	1	0
8	....	....	....	....	....	....	....	....
9	....	....	....	....	....	....	....	0
10	....	....	....	....	....	....	....	0.5
11	....	....	....	....	....	....	...[g]	0.5
12	2	3	2	2.5	1	1	2	0.5
13	....	....	....	....	....	....	2	0.5
14	....	....	....	....	....	....	....	0.5
15	....	....	....	....	....	....	2	0.5
16	1	0	1	0	2	0	2	0.5
17	0.5	0	1	0	2	0	3	0.5
18	0.5	0	0.5	0	1.5	0	1	0
19	0.5	0.5	0.5	0	1	0.5	1	0
20	....	....	....	....	....	....	1	0
21	....	....	....	....	....	....	....	0
22	....	....	....	....	....	....	....	0
23	....	....	....	....	....	....	2	0
24	....	....	....	....	....	....	4	0
25	....	....	....	....	....	....	....	0.5
26	1.5	0.5	1.5	0.5	1	0.5	5	0
27	....	....	....	....	....	....	2	0
28	....	....	....	....	....	....	....	0.5
29	1	2	0.5[d]	1[d]	1[d]	0[d]	2	0.5
30	1	2	0.5	1	1[d]	1[d]	1[g]	1.0
31	....	....	....	....	....	....	....	0.5
Mean	0.9	0.8	0.9	0.7	1.0	0.6	1.8	0.4

[a] Very bright $H\alpha$ south group. [b] Small areas very bright K_2 and $H\alpha$ large northeast group. [c] Small areas very bright K_2 and $H\alpha$ large northwest group. [d] Low weight. [e], [f], [g] Passage of an average-sized group through the central meridian within 5°, 10°, 15° of the center of the disc, respectively.

Mount Wilson Observatory, Pasadena, California

SETH B. NICHOLSON
ELIZABETH E. STERNBERG

PROVISIONAL SUNSPOT-NUMBERS FOR NOVEMBER, 1931, TO FEBRUARY, 1932

(Dependent alone on observations at Zürich Observatory and its station at Arosa)

Day	Nov.	Dec.	Jan.	Feb.	Day	Nov.	Dec.	Jan.	Feb.
1	8	20	12	19	17	8	15	12	0
2	14	16	25	16	18	14	8	8	0
3	*E*17[c]	7?	..	17	19	10	8	7	0
4	18	..	8	8	20	16[d]	8	0	0
5	24	0	8	8	21	29	8	8[d]	0
6	..	*E* 7[c]	0?	8	22	39	16	18	0
7	13[a]	12	0?	7	23	33	17	17	*E*18[c]
8	12	13	..	7	24	..	23[d]	16	23
9	16	24	0	..	25	44	31	25	26
10	0	*E*..[c]	7	9	26	*M*42[bc]	31	42[d]	26
11	0	35[a]	0?	9	27	34[a]	31	36[a]	39[d]
12	0	37	0	7	28	31	15	18	31
13	0	38[a]	0	0	29	..	9	18	29
14	0	37	*M*..[c]	0	30	26	11[a]	18	
15	..	26	10	0	31		9	17	
16	0	..	15	0					
					Means	17.2	18.3	12.3	11.0
					No. days	26	28	28	28

Mean for quarter January to March, 1931: 28.4 (75 *days*)
April to June, 1931: 23.4 (88 *days*)
July to September, 1931: 16.6 (88 *days*)
October to December, 1931: 15.0 (82 *days*)
Mean provisional sunspot-number for year 1931: 20.7 (333 *days*)

a Passage of an average-sized group through the central meridian.
b Passage of a larger group through the central meridian.
c New formation of a large or average-sized center of activity; *E*, on the eastern part of the Sun's disc; *W*, on the western part; *M*, in the central zone.
d Entrance of a large or average-sized center of activity on the east limb.

Zürich, Switzerland W. Brunner

AMERICAN *URSI* BROADCASTS OF COSMIC DATA[1]

The data for terrestrial magnetism, sunspots, solar constant, and aurora are the same as given in previous tables.

The first three columns of the Table give (1) the magnetic character according to the scale 0-2 of the International Commission of Terrestrial Magnetism and Electricity, (2) the type featuring the day other than normal by the letters *b*, *p*, *o*, and *i* for days marked by bay, rapid pulsations, long-period oscillations, and irregular oscillations, respectively, and (3) the hour and minute of Greenwich mean time marking the beginning of a storm, the end of the storm being indicated in the footnote to the Table. The next two columns give the data relating to sunspots: (1) the number of groups of spots and (2) the total number of spots. It is to be noted that sunspot-numbers such as those from Zürich can be obtained from the number of groups and spots given in the Table by the formula $N=k\ (10g+s)$, where k for Mount Wilson is about 0.77. The sixth and seventh columns show (1) the value in calories of the solar constant, and (2) by letters s, f, and u, whether the determination was satisfactory, fair, or unsatisfactory, respectively.

[1] For previous announcements see Terr. Mag., **35**, 184-185 and 252-253 (1930); **36**, 54, 141, 258-259, and 358-360 (1931).

Summary American URSI daily broadcasts of

Date	November																	December						
	Magnetism			Sun-spot		Solar constant		Aurora										Magnetism			Sun-spot		Solar Constant	
	Char.	Type	G. M. T. begin. distur.	Groups	No.	Value	Char.	Char.	Duration	Cloudiness	Form without rays	Form with rays	Area covered	Av. altitude	Position	G.M.T. greatest distur	Char.	Type	G. M. T. begin. distur.	Groups	No.	Value	Char.
			h m			cal*			hrs					°		h			h m			cal*	
1	0	...	...	1	2	...	...	9	...	10	...	...	...	...	...	...	0	...	...	2	5	...	...
2	0	...	...	2	4	...	...	1	2	7	*HA*	*RB*	0.4	30	NW-NE-SE	14	0	...	...	2	5	...	.
3	0	...	...	2	9	...	...	1	1	8	*G*	*RA*	0.2	15	NW-N-NE	6	1	*i*	...	1	2	...	...
4	1	*b*	6 35	2	8	...	...	1	1	9	*HB*	...	0.2	60	NW-Z-SE	5	1	*i*	...	0	0	...	...
5	0	...	...	2	16	...	...	3	5	2	*HV*	*RV*	0.6	75	NW-NE-SE	8	1	*p*	...	0	0	...	...
6	1	*p*	...	2	13	...	...	3	10	2	*HV*	*RV*	0.4	45	NW-NE-E	8	0	...	...	1	4	...	.
7	1	*p*	...	...	...	...	...	9	...	10	...	...	...	...	...	...	0	...	...	1	12	...	...
8	1	*o*	4 55	1	4	...	...	3	6	1	*HV*	*RV*	0.4	40	NW-NE-E	8	0	...	...	...	...	...	...
9	1	*i*	...	3	5	...	...	1	4	9	*G*	...	0.4	35	NW-NE-E	12	0	...	...	...	...	...	...
10	1	*o*	1 ...	...	...	...	...	1	1	8	*G*	...	0.2	25	NW-N-NE	10	1	*b*	7 40	...	...	...	...
11	0	...	...	...	...	...	...	9	...	8	...	...	...	...	...	...	0		.	2	14	...	
12	0	...	...	0	0	...	.	0	0	6	...	...	...	...	...	...	0						
13	0	...	...	0	0	...	...	1	2	7	*HV*	*R*	0.4	65	NW-N-NE	13	0			2	20		
14	0	...	...	0	0	...	...	1	10	4	*HV*	*RV*	0.4	60	W-N-E	12	0					.	
15	0	...	...	...	...	...	...	1	5	0	*HV*	*RV*	0.8	75	NW-N-E	9	0			2	5		
16	1	*i*	...	1	3	...	...	1	5	8	*HV*	*RV*	0.6	35	NW-N-E	14	0	...	...	2	5	...	
17	1	*i*	...	1	4	...	...	1	6	6	*HV*	*RV*	0.4	35	NW-N-E	14	0	...	...	2	3	...	
18	1	*i*	...	2	4	...	...	3	11	0	*HV*	*RV*	0.6	75	W-N-SE	11	0	...	...	...	...	...	
19	0	...	...	1	3	...	...	1	8	0	*HV*	*RV*	0.6	75	NW-N-E	14	0						
20	0	...	...	2	5	...	...	1	6	3	*HA*	...	0.4	30	NW-N-E	7	0	.	...	...	...	...	
21	0	...	...	...	...	...	...	9	...	10	...	...	...	...	...	...	0	...	...	...	...	...	
22	0	...	...	...	...	...	...	9	..	10	...	...	...	...	...	...	0	...	...	...	...	.	
23	0	...	...	4	18	...	...	1	1	6	*HA*	*RB*	0.2	8	NW-N-NE	11	0	...	...	4	10	.	
24	0	...	...	...	...	...	...	9	...	10	...	...	...	...	...	...	0	...	...	...	...	...	
25	0	...	...	2	14	...	...	9	...	10	...	...	...	...	...	..	1	*i*	1 00				
26	1	*i*	...	...	...	...	...	1	1	6	*G*	*RB*	0.2	40	W-N-E	12	0	...	...	..			
27	1	*p*	...	...	...	...	...	1	1	9	...	*RB*	0.2	10	N-NE-E	7	0	...	...	...	...	..	
28	0	...	...	2	12	...	...	9	...	10	...	...	...	...	...	...	0	..	...	...	...	.	
29	0	...	...	2	10	...	...	3	1	5	*HB*	*RB*	0.2	35	NW-N-NE	12	1	*i*	...	2	4	.	
30	0	...	...	2	8	...	...	0	0	7	...	...	...	...	...	...	1	*i*	...	1	6		
31																	1	*i*					
Mean	0.4	...	...	1.6	7.9	...	...	1.4	4	6	...	...	...	...	...	10	0.3	...	...	1.6	6.3	.	

Greenwich mean time for endings of storms: 7^h35^m, Nov. 4; 5^h, Nov. 9; 7^h, Nov. 10; 1^h, Dec. 5; 8^h50^m, Dec. 10;
* Due to instrument damage at Chile Station, solar constants are temporarily omitted.

Under the general heading of aurora in the table, the first column gives the character of the day: 0 indicates no aurora; 1, faint; 3, moderate; 5, strong; 7, brilliant; and 9, no observation or no observations possible on account of cloudiness. The second column gives the number of hours during which aurora was present. The third column indicates the amount of sky covered by cloud on a scale of 0-10, where 0 means cloudiness, and 10 completely overcast.

Columns four and five describe by letters the form of the aurora, column four indicating forms without ray structure and column five, forms with ray structure. The letters employed are the same as those used in the Photographic Atlas of Auroral Forms published by the International Geodetic and Geophysical Union, Oslo, 1930, so far as it was possible to use those letters. For forms without ray structure *HA* indicates homogeneous quiet arcs; *HB*, homogeneous bands; *PA* pulsating arcs; *DS*, diffuse luminous surfaces; *PS* pulsating surfaces; *G*, feeble glow; *HV*, varied forms; *HF*, flaming aurora, and *HVF*, varied forms with flaming. For forms with ray structure *RA* indicates arcs; *R* , bands; *D*, draperies; *R*, rays; *C*, corona; *RV*, varied forms; *RF*, flaming aurora; and *RVF*, varied forms with flaming.

smic data, November 1931 to January 1932

December								January														
Aurora								Magnetism			Sunspot		Solar constant		Aurora							
Duration	Cloudiness	Form: without rays	Form: with rays	Area covered	Av. altitude	Position	G.M.T. greatest distur.	Char.	Type	G. M. T. begin. distur.	Groups	No.	Value	Char.	Char.	Duration	Cloudiness	Form: without rays	Form: with rays	Area covered	Av. altitude	Position
hrs					°		*h*			*h m*			*cal**			*hrs*					°	
4	0	*HV*	*RV*	0.6	45	*NW-NE-SE*	12	0	..	.. ....	3	6	.....	..	1	7	3	*HV*	*R*	0.4	20	NW-NE-E
8	6	*HV*	*RV*	0.4	60	*NW-N-E*	11	1	*i*	.. ....	2	5	.....	..	3	11	5	*HV*	*RV*	0.6	25	NW-NE-E
11	3	*HV*	*RV*	0.6	75	NW-NE-SE	10	1	*i*	.. ....	3	5	.....	..	1	8	1	*HV*	.....	0.4	20	NW-NE-E
..	10	.....	.....	...	...	....	...	0	..	.. ....	2	3	.....	..	1	2	2	*HA*	.....	0.2	10	NW-N-NE
1	8	*PA*	.....	0.2	30	NW-N-NE	12	0	..	.. ....	1	1	.....	..	1	3	3	*HA*	.....	0.2	18	NW-NE-E
1	8	*HA*	.....	0.2	21	NW-NE-SE	11	0	..	.. ....	1	3	.....	..	0	0	9					
1	7	*HA*	.....	0.2	45	NW-NE-E	12	0	..	.. ....	0	0	.....	..	1	1	4	*HA*		0.2	30	N-NE-E
...	10	.....	.....	...	...	....	...	1	*i*	5 05	...	...	.....	..	3	9	4	*HV*	*RV*	0.8	85	NW-NE-E
1	9	*HA*	.....	0.2	20	N-NE-E	6	1	*p*	.. ....	0	0	.....	..	3	9	6	*HV*	*RV*	0.6	80	NW-N-E
1	10	.....	*RB*	0.2	60	NW-NE-E	8	1	*p*	.. ....	0	0	.....	..	1	4	3	*HV*	*RV*	0.6	30	N-NE-E
...	10	.....	.....	...	...	....	...	0	..	.. ....	1	2	.....		1	9	2	*HV*	*RV*	0.4	45	W-NE-E
4	7	*HV*	*RV*	1.0	45	NW-E-A	15	0	..	.. ....	...	...	.....	..	9	...	10	.....	.....	...	...	....
.	10							0							9	.	10	..				
4	4	*HV*	*R*	0.4	20	NW-NE-E	12	0	..	.. ....	1	2	.....	..	9	...	10	.....	.....	...	...	....
7	0	*HV*	*RV*	0.6	25	NW-NE-E	10	0	..	.. ....	...	...	.....	..	3	10	3	*HV*	*RV*	0.6	40	W-NE-E
1	9	*G*	.....	0.2	10	NE	6	0	..	.. ....	1	10	.....	..	1	7	1	*HA*	*R*	0.2	20	NW-N-E
1	9	*G*	*RB*	0.4	30	NW-N-E	12	0	..	.. ....	...	...	.....	..	1	10	1	*HA*	*R*	0.4	20	NW-N-E
2	3	*HA*	*RB*	0.2	25	NW-NE-E	12	0	..	.. ....	1	1	.....	..	1	1	5	*HB*	.....	0.2	15	NW-N-NE
0	3	.....	.....	...	...	....	...	0	..	.. ....	1	1	.....	..	0	0	3	.....	.....	...		
...	10	.....	.....	...	...	....	...	0	..	.. ....	...	...	.....	..	1	3	2	*HA*	*RB*	0.2	25	NW-N-E
...	10	.....	.....	...	...	....	...	0	..	.. ....	1	1	.....	..	1	1	6	.....	*RB*	0.2	12	NW-N-NE
...	10	.....	.....	...	...	....	...	0	..	.. ....	2	6	.....	..	9	...	10	.....	.....	...	...	....
0	6	.....	.....	...	...	....	...	0	..	.. ....	...	...	.....	..	9	...	10	.....	.....	...	...	....
1	4	*HA*	.....	0.2	10	W-NE-E	13	0	..	.. ....	...	...	.....	..	9	...	10	.....	.....	...	...	....
1	5	.....	*RB*	0.2	60	NW-N-NE	12	1	*i*	.. ....	2	4	.....	..	1	4	1	*HV*	*RV*	0.2	60	NW-N-E
2	3	*HA*	*R*	0.2	10	N-NE-E	11	1	*i*	.. ...	...	...	.....	..	1	3	0	*HA*	*RB*	0.2	40	NW-N-E
...	10	.....	.....	...	...	....	...	1	*i*	.. ....	4	7	.....	..	9	..	10	.....	.....	...	...	....
...	10	.....	.....	...	...	....	...	1	*p*	.. ....	...	...	.....	..	5	9	0	*HV*	*RV*	0.6	75	W-N-E
3	5	*HV*	*RV*	0.6	85	W-N-E	13	1	*i*	.. ....	2	3	.....	..	1	7	3	*HV*	*RV*	0.4	60	NW-NE-E
12	0	*HV*	*RV*	0.8	70	W-N-SE	10	0	..	.. ....	...	...	.....	..	9	...	10	.....	.....	...	...	....
12	0	*HV*	*RV*	0.6	30	NW-NE-E	10	0	..	.. ....	...	...	.....	..	9	...	10	.....	.....	...	...	....
4	6	.....	.....	...	...	....	11	0.3	..	.. ....	1.5	3.2	.....	..	1.4	5	5	.....	.....	...	...	....

Jan. 10.

Column six gives the maximum area of sky covered in tenths of the whole sky, column seven the average altitude in degrees, and column eight the general position of the aurora, being reckoned for included positions in a clockwise direction with *Z* representing zenith and *A* the whole sky. The final column gives the Greenwich mean hour of the observed greatest display in the preceding 24 hours of the Greenwich day.

Please note that in the table of cosmic data for August, September, and October (see this JOURNAL, **36**, pp. 358-359) the dates for auroral data are in error by one day. In the transmission of the data in code local day was used. As all other data of the *URSI* broadcasts are given for the Greenwich day, the dates as previously given for the auroral data should be moved ahead one day (that is, August 13 should be August 14, etc.) in order that they may correspond with other data given for the Greenwich day. In the following table all observations, including aurora, are given for the Greenwich day.

The table of Kennelly-Heaviside Layer heights is self-explanatory.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON,
Washington, D. C.

KATHARINE B. CLARKE

Kennelly-Heaviside Layer heights, Washington, D. C.

Date	Frequency	Nearest hour G.M.T.	Height
1931	*kc/sec*	*h*	*km*
Nov. 6	4,100	18	110, 230
" "	5,000	19	110, 220
" "	6,000	21	230
" 10	1,600	4	300
" "	3,000	3	110, 300
" "	4,100	3	140, 360
" "	4,750	3	140, 360, 620
" "	5,000	3	No value obtained
" 12	1,600	14	110
" "	3,000	14	120, 210
" "	4,100	15	140, 240
" "	5,000	15	150, 240
" "	6,000	15	240
" "	7,000	15	240
" "	8,000	15	210, 580
" "	8,500	16	660
" "	9,500	16	110
" "	10,000	16	110
" 18	2,500	17	130
" "	4,100	17	120, 210, 390
" "	5,000	18	120
" "	5,500	18	100, 250
" "	6,000	19	240
" "	4,100	3	110
" "	2,600	2	150, 280
" 24	4,100	15	250
" "	5,000	16	250
" "	5,900	16	250
" "	6,800	16	290
" "	7,930	17	340
" "	9,000	18	690
" "	9,400	18	730
" "	9,600	18	No value obtained
" "	1,600	20	" " "
" "	2,000	20	110
" "	3,000	21	110
" 25	1,600	2	140, 260
" "	3,000	2	100, 290
" "	4,100	2	330
" "	4,500	2	480
" "	4,950	2	No value obtained
Dec. 2	1,600	22	130
" "	3,000	22	140, 230
" "	4,100	22	250
" "	5,500	22	260
" "	6,500	22	290
" "	7,500	22	400, 450
" "	8,000	22	720
" "	8,500	22	850
" "	9,000	22	920
" "	10,000	17	780
" "	11,000	17	820
" 3	1,600	3	290
" "	3,000	3	300
" "	4,100	3	420
" "	4,500	3	470
" "	5,250	3	130
1931	*kc/sec*	*h*	*km*
Dec. 3	5,500	3	No value obtained
" 8	10,000	19	" " "
" "	9,000	19	900
" "	8,000	19	680
" "	6,900	19	320
" "	4,100	20	110, 240
" "	3,000	20	100, 220
" "	2,500	20	110, 300
" "	2,000	20	110
" "	1,600	20	100
" 17	1,600	10	220
" "	2,000	10	110
" "	3,000	10	100
" "	4,100	11	110
" "	5,000	11	140
" "	6,500	11	140
" "	9,000	11	110
" "	10,000	11	110
" "	11,000	11	180
" "	1,600	19	110
" "	2,000	19	110
" "	3,000	19	110, 230
" "	4,100	19	110, 240
" "	5,500	20	240
" "	6,900	20	290
" "	7,500	20	690
" "	8,500	20	860
" "	9,000	20	No value obtained
" 21	1,600	19	" " "
" "	2,000	19	110
" "	3,000	19	110, 230
" "	4,100	19	110, 230
" "	5,500	19	110, 270
" "	6,500	19	340
" 29	1,600	19	No value obtained
" "	2,000	19	110
" "	2,500	19	110
" "	3,000	19	110, 210
" "	3,450	19	110, 250
" "	4,100	19	110, 270
" "	5,500	19	270
" "	6,500	19	280
" "	6,900	19	300
" "	7,610	19	820
" "	7,900	19	750
" "	8,200	19	No value obtained
" 30	1,600	0	110, 240
" "	2,500	0	110, 310
" "	3,000	0	100, 340
" "	4,100	0	110, 430
" "	5,050	0	490
" "	5,500	0	560
" "	5,900	0	No value obtained
1932			
Jan. 4	1,600	20	110
" "	2,400	20	110
" "	3,000	20	110, 210

Kennelly-Heaviside Layer heights, Washington, D. C.

Date	Frequency	Nearest hour G.M.T.	Height	Date	Frequency	Nearest hour G.M.T.	Height
1932	*kc/sec*	*h*	*km*	*1932*	*kc/sec*	*h*	*km*
Jan. 4	3,450	20	110, 230	Jan. 19	1,900	22	130, 220
" "	4,100	20	240	" "	2,500	22	240
" "	5,050	20	250	" "	3,000	21	210
" "	5,900	19	280	" "	3,450	21	220
" "	6,900	19	320	" "	4,100	21	230
" "	8,000	19	340	" "	5,050	21	290
" "	8,500	19	No value obtained	" "	5,500	20	280
" 12	1,600	20	" " "	" "	6,000	20	740
" "	3,000	20	110, 210	" "	6,150	20	660
" "	3,450	20	110, 240	" "	6,000	20	310
" "	4,100	20	110, 240	" 26	2,500	20	230
" "	5,050	20	110, 250	" "	3,000	20	230
" "	5,500	20	250	" "	3,450	20	240
" "	5,900	20	250	" "	4,100	20	250
" "	6,500	19	250	" "	5,050	20	290
" "	6,900	19	310	" "	5,500	20	300
" "	8,000	19	780	" "	6,000	20	360
" "	9,300	19	850	" "	6,500	19	830
" "	9,500	19	No value obtained	" "	6,900	18	890
" 19	1,800	22	110, 200	" "	8,000	18	No value obtained

PRINCIPAL MAGNETIC STORMS

Sitka Magnetic Observatory
October to December, 1931[1]

(Latitude 57° 03′.0 N.; longitude, 135° 20′.1 or 9^h 01^m.3 W. of Gr.)

Greenwich mean time		Greenwich mean time		Range		
Beginning		Ending		Decl'n	Hor. int.	Ver. int.
1931	*h m*	*d*	*h m*	′	γ	γ
Oct. 2	9 ..	Oct. 3	09 ..	66.2	405	408
Oct. 4	8 ..	Oct. 6	05 ..	88.6	514	596
Oct. 12	6 12	Oct. 14	14 ..	67.7	507	448
Nov. 5	7 55	Nov. 6	14 ..	73.4	533	425
Nov. 26	9 ..	Nov. 27	13 ..	85.0	395	597

There were no large magnetic storms during this quarter, all of the storms being only mildly active for some time or moderately active for short periods.

October 2-3, 1931—This storm has no particular characteristic except that it is mildly active from 13^h to 17^h on October 2.

October 4-6, 1931—This storm is only mildly active except that it has two quite active periods between 3^h and 6^h and between 7^h and 10^h on October 5.

[1] Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

October 12-14, 1931—The time of beginning of this storm is not a particularly definite point but the beginning is rather gradual from this point. This storm is moderately active from October 12, 23^h to October 14, 16^h.

November 26-27, 1931—There are no particularly interesting features about this storm except that it has a moderately active period from 12^h to 16^h on November 26.

Franklin P. Ulrich, *Observer-in-Charge*

Cheltenham Magnetic Observatory
October to December, 1931[1]

(Latitude 38° 44'.0 N.; longitude 76° 50'.5 or $5^h\ 07^m.4$ W. of Gr.)

There were no large magnetic disturbances during the quarter. A mild storm began at about 5^h, G. M. T., October 29, and continued to about 22^h, October 30; the ranges were 57.7′, 196γ, and 141γ in declination, horizontal intensity, and vertical intensity, respectively.

Geo. Hartnell, *Observer-in-Charge*

Huancayo Magnetic Observatory
September to December, 1931

(Latitude 12° 02'.7 S.; longitude 75° 20'.4 or $5^h\ 01^m$ W. of Gr.)

October 29-30, 1931—A mild magnetic storm was recorded beginning October 29 at $8^h\ 39^m$ (Greenwich mean time). At that time the *H*-trace showed a slow upward trend of 13γ occupying 6 minutes; thereafter the element was mildly oscillatory and decreased steadily. At about $11^h\ 50^m$ large slow movements began to take place and continued until approximately 22^h. The storm showed no definite termination, the elements remaining considerably disturbed until 22^h on October 31. The month was generally disturbed, but an ending to the storm might be placed tentatively at $21^h\ 20^m$ on October 30. During the progress of the disturbance the *D* and *Z* elements showed some irregularities. The normal maximum in *H* was entirely obliterated on the 29th, but it showed itself on the 30th, though somewhat depressed. The range of the storm was 227γ in *H*, though over the most disturbed period, from the commencement to 22^h on the 29th, the range was only 186γ.

Paul G. Ledig, *Observer-in-Charge*

Watheroo Magnetic Observatory
September to December, 1931

(Latitude 30° 19'.1 S.; longitude 115° 52'.6 or $7^h\ 43^m.5$ E. of Gr.)

October 29, 1931—A mild storm commenced at $7^h\ 43^m$ (Greenwich mean time) on October 29 and ended at $21^h\ 40^m$ the same day. It was followed by a slight disturbance the next day. The total ranges were as follows: Declination, 19′; horizontal intensity, 120γ; vertical intensity, 160γ.

W. C. Parkinson, *Observer-in-Charge*

[1] Communicated by R. S. Patton, Director, United States Coast and Geodetic Survey.

REVIEWS AND ABSTRACTS

INTERNATIONAL RESEARCH COUNCIL: *Third report of the Commission appointed to further the study of Solar and Terrestrial Relationships.* London, Percy Lund, Humphries and Co., 1931 (v+132). 22 cm.

This is the third of the reports of the Commission to the International Research Council, the first two having been printed and circulated in 1926 and 1929. The report proper, covering the first three pages, deals briefly with the following topics: Publication of the second report, constitution of the Committee, bulletins of daily character-figures for solar phenomena, the proposed International Polar Year of 1932-1933, daily magnetic character-figures, memoranda on recent progress, and ultraviolet solar-radiation. The remaining 129 pages of the publication contain forty articles by various authors, of which the following may be mentioned as of especial interest to readers of the JOURNAL: S. Chapman, Solar influences on the Earth's magnetism and on the upper atmosphere; L. d'Azambuja, Sur l'observation des phénomènes éruptifs dans le chromosphère solaire et leurs relations avec les orages magnétiques; H. W. Fisk, Magnetic secular-variation and solar activity; J. A. Fleming, Researches of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington bearing on solar activity and the Earth's magnetic and electric fields; W. M. H. Greaves, Discussion of the Greenwich solar and magnetic data; R. Gunn, Review of certain contributions to solar and terrestrial magnetism; L. Harang, Memorandum on investigations of aurora at Nordlysobservatoriet (Auroral Observatory), Tromsö; E. O. Hulburt, The ultraviolet-light theory of aurorae and magnetic storms; V. A. Kostitzin, On the relation of magnetic agitation to solar activity; M. et Mme. H. Labrouste, Composantes périodiques de l'activité solaire et composantes correspondantes dans le magnétisme terrestre; J. C. McLennen, On the auroral green line; D. H. Menzel, Auroral phenomena and the solar chromosphere; H. T. Stetson, The correlation of solar and lunar phenomena with the ionization of the Earth's atmosphere; C. Störmer, Auroral research.

Professor S. Chapman, the first chairman of the Commission, and himself a successful worker in this field, deserves high credit for editing these reports. By inviting the investigators to contribute summaries of their work, he has made the reports fairly complete compendia of the status of our knowledge regarding solar and terrestrial relationships. That this is a distinct help to individual research as well as to collaboration is obvious, considering the fact that the papers on this subject are scattered in physical, geophysical, astronomical, and meteorological journals.

The report is neatly reproduced by the planograph method which, on account of convenience and economy, is now becoming more widely used for publications of this character.

H. D. HARRADON

WILSON, W. *Theoretical physics.* Vol. I. Mechanics and heat, Newton-Carnot. New York, E. P. Dutton, 1931 (x+332 with 80 diagrams). 22 cm.

This book, the first of a three-volume treatise, is devoted to the classical phases of mechanics and heat. As there is really nothing available of recent date having the scope and character of this work, it should meet with distinct approval.

Apparently the volume is intended primarily as an advanced text-book, and, as such, it should be most excellent. However, the research worker should also find it valuable. The subject matter is arranged in a logical and graded manner. From a discussion of the simplest concepts, the author leads up to the more general principles of classical mechanics and heat. The development of each topic follows roughly its historical growth. The greater part of the material should be familiar to every graduate student in physics, even though he has no intention of specializing in theoretical physics.

No elaborate preparation in physics and mathematics is necessary for a profitable reading of the volume; the knowledge of physics, calculus, and analytical geometry ordinarily possessed by a junior or senior in an American college should quite suffice. More advanced mathematical principles are developed as needed. The chapter on tensor-analysis is to be especially commended, not only because of the clear presentation of the subject, but because a familiarity with it is necessary if one wishes to follow theoretical physics.

After the chapter on tensor-analysis, the theorems of Gauss, Green, and Stokes are discussed. Fourier expansions and orthogonal functions are also introduced here. The chapter on dynamics treats the ordinary topics usually included in a book on classical dynamics and a chapter on wave-propagation includes a brief statement of the principles underlying wave-mechanics. Electricity, hydrodynamics, and motion in viscous fluids are treated quite extensively and tensors, explained in the earlier chapter, are used to advantage here. The remainder of the book covers the subjects

of kinetic theory, statistical mechanics, and thermodynamics. The first two laws of thermodynamics are treated quite fully; the third law, however, is no more than mentioned. The final chapter is devoted to the application of thermodynamical principles to the derivation of the usual formulas.

The reviewer can make no serious adverse criticism of the book. However, it seems as though further references as well as some problems including illustrative examples, might have been given. L. E. Loveridge

Moidrey, J. De: *Études sur le magnétisme terrestre à Zi-ka-wei et à Lu-kia-pang.* 1877-1929. Etude XXXIX. Chang-hai, 1931. 24 pp. 32 cm.

This new study by Rev. J. de Moidrey, S.J., deals with the secular variation in the Far East—covering nearly the whole western coast of the Pacific from the Arctic Ocean to Australia. The subject is treated chronologically in three periods. The first period embraces the early times when only accidental remarks from local writers are available; information for this period is very meager. The second period, from the seventeenth to the beginning of the present century, contains a discussion of observations of declination and dip obtained by travelers and missionaries when there were no fixed observatories. Four maps have been constructed showing successive positions of the agonic line from 1600 to 1927. These are clearly shown, although in some places the lines appear rather intricate, owing, perhaps, to the fact that in the region considered the variation was always very small. In the third period, that of recording observatories, eleven stations are dealt with, although at four of these, absolute observations only were available for a part or all the time. For each of these stations the following data are given as far as possible. (1) The yearly means: Instructive diagrams show distinctly how far secular changes are from being linear, although there is a marked similarity at some stations, namely, Hongkong, Lukiapang, Tsingtao, or even Kakioka, from 1916 onwards; the necessity of repeat-stations is conspicuous, although it is not so important in the region studied as in countries of much more rapid change. (2) The annual variation: This varies greatly at different stations; this variation is shown by three plates for D, I, and H, respectively, which may furnish data for the study of correlations with solar phenomena. (3) The differences between each station and a neighboring one, with three plates of D, I, and H, are given. The pamphlet is concluded with a few general remarks on the subject under investigation. [Author's abstract.]

Röstad, A.: *Ueber magnetische Störungen die an südnorwegischen Nordlichttagen in Potsdam beobachtet wurden.* Geofys. Pub., Oslo, v. 9, No. 3, 1931 (30 with 28 figs.).

In this paper the author presents the results of a statistical study of magnetic disturbances. The work is divided into two parts: (a) Relation between the aurora and magnetic disturbances, and (b) special characteristics of magnetic disturbances.

The auroral data consisted of measurements of the angle θ published by Störmer for auroral observation in southern Norway during 1911-22, θ being the angle between the Earth's magnetic axis and some prominent point in the aurora as seen from the center of the Earth. The magnetic disturbing forces were computed from the records of Potsdam and Tucson. The curves representing the relation between θ and the intensity of magnetic disturbance show naturally an increase in θ with increase in magnetic activity, but for Potsdam the curve is rectilinear whatever the type of aurora (rays, arcs, or diffused arcs), while for Tucson the curve is of a parabolic type. The author believes that this was to be expected from theoretical considerations.

For the study of special characteristics of magnetic disturbances, hourly values of the disturbing force P were computed for 144 disturbed days between 1891 and 1922. The force P is referred to three rectangular axes with origin at the point of observation, one axis being parallel to the Earth's magnetic axis, the second perpendicular to the magnetic axis, and the third perpendicular to the other two. The components of P along these axes are respectively P_a, P_r, and P_c. The 144 disturbed days are divided into seven groups according to intensity of disturbance. With these data a variety of investigations are carried out, namely, diurnal-variation curves of P are developed for different intensity groups, also diurnal-variation curves of P_a/P, P_r/P, and P_c/P, diagrams showing momentary frequency-distributions of direction of disturbing force, diagrams showing diurnal variations of the projections of the angle $\cos^{-1} P_a/P$ (ϕ and ψ) on the two vertical coordinate planes, curves representing the relation between θ and P_a, and finally curves resulting from a study of irregular short-period fluctuations. The author contributes a full and interesting discussion of the diagrams, pointing out their noteworthy features and attempting to discover their physical meanings. W. F. Wallis

LIST OF RECENT PUBLICATIONS

By H. D. Harradon

A—Terrestrial and Cosmical Magnetism

Agincourt and Meanook Observatories. Results of observations at the Canadian Magnetical Observatories, Agincourt and Meanook. The year 1925. Prepared by W. E. W. Jackson. Ottawa, F. A. Acland, 1931 (42 with pls.). 29 cm.

Alexanian, M. C. Practical rules for the use of the magnetometer in geophysical prospecting. Washington, D. C., Dept. Comm., U. S. Bur. Mines, Inf. Cir. 6527, 1931 (19). [Translation by W. Ayvazoglou of the original article in Ann. Office Nation. Combustibles Liquides, Paris, v. 5, No. 4, 1930, pp. 677-702.]

Baseler, O. Die Vermessung der erdmagnetischen Anomalie bei Pr.-Eylau in Ostpreussen und ein Versuch ihrer Deutung. Beitr. Geophysik, Leipzig, Ergänzungshefte, Bd. 2, Heft 1, 1931 (69-121).

Bates, L. F. A simple apparatus for the measurement of the horizontal component of the Earth's magnetic field. London, J. Sci. Instr., v. 8, No. 10, 1931 (324-326). [Description of a simple piece of apparatus for the determination of horizontal intensity based on the method used by A. Schuster and F. E. Smith. In the form described it is intended mainly for use in teaching laboratories.]

Bock, R. Ein neuer Schulzescher Erdinduktor. Zs. Instrumentenk., Berlin, Jahrg. 52, Heft 2, 1932 (85-86).

Comité National Français de Géodésie et Géophysique. Compte rendu de l'Assemblée Générale du 9 mars 1931, publié par le Secrétaire Général G. Perrier. Paris, Au Secrétariat Général du Comité, 1931 (93). 24cm. [Annexe 4, pp. 56-68, contains a general report on the activities of the French Section of Terrestrial Magnetism and Electricity.]

De Bilt, Institut Météorologique Royal des Pays-Bas. Caractère magnétique numérique des jours. Tome 1, Janvier-décembre 1930. De Bilt, 1932, 40 pp. 24 cm. [First publication, under the auspices of the Association of Terrestrial Magnetism and Electricty of the International Union of Geodesy and Geophysics, of the numerical character of days obtained by use of the formulas adopted at the Stockholm meeting of the Association in 1930. In this publication data from ten magnetic observatories are published.]

Egypt, Physical Department. Meteorological report for the year 1925. Cairo, Ministry Pub. Works, Physical Dept., 1931 (xiii+176). 32 cm. [Contains values of the magnetic elements at Helwan Observatory for 1925.]

Eickelberg, E. W. New system of conducting magnetic survey. Washington, D. C., U. S. Coast Geod. Surv., Assoc. Field Eng., Bull. No. 4, 1931 (87). [Note regarding practice adopted by the U. S. Coast and Geodetic Survey of using the same points for the magnetic and triangulation work.]

Hazard, D. L. Results of observations made at the United States Coast and Geodetic Survey Magnetic Observatory at Cheltenham, Maryland, in 1925 and 1926. Washington, D. C., Dept. Comm., U. S. Coast Geod. Surv., Ser. No. 523, 1931 (100 with 14 figs.). 27 cm.

Results of observations made at the United States Coast and Geodetic Survey Magnetic Observatory near Honolulu, Hawaii, in 1925 and 1926. Washington, D. C., Dept. Comm., U. S. Coast Geod. Surv., Ser. No. 522, 1931 (107 with 13 figs.). 27 cm.

Immler, W. Der Kompass im veränderlichen Magnetfeld. Ann. Hydrogr., Berlin, Jahrg. 59. Heft 8, 1931 (277-292).

India, Survey of. Geodetic report. Volume 6. From 1st October 1929 to 30th September 1930. Published under the direction of Brigadier R. H. Thomas, D.S.O., Surveyor General of India. Dehra Dun, Geod. Branch Office, 1931 (xi+106 with 24 charts and pls.). 25 cm. [An account of the magnetic observations made during 1929 at Dehra Dun Observatory is given on pages 9-13. The usual program was carried out consisting of a continuous magnetograph record of declination, horizontal force, and vertical force, daily observations of dip, and biweekly observations of declination and horizontal force. The results are summarized in tables 9-17. With the exception of the observations at Dehra Dun and Alibag observatories, no magnetic work has been done in India since 1922.]

KOHL, E. Ueber die Ermittlung tektonischer Linien mittels der magnetischen Feldwaage in Gebieten geringer Unterschiede der magnetischen Vertikalintensität, im besonderen in Norddeutschland. Kali, Berlin, Bd. 25, 1931 (209-215, 225-230, 241-243).

LE CAMUS, C., ET F. DE SAINT-JUST. Observations magnétiques et électriques au Sahara. Paris, C.-R. Acad. sci., T. 193, No. 15, 1931 (600-601). [The three magnetic elements were observed at three stations: Gao, Tanesrouft, and Camp Louis Marin (Hoggar) in the course of a journey to the Sahara during December 1930 and January 1931. Potential-gradient observations were also obtained at the same stations.]

LEE, F. W. Results of some magnetic measurements on dikes, with experiments upon geophysical differentiation of nickel-ore deposits in the Sudbury District, Ontario, Canada. Washington, D. C., Dept. Comm., U. S. Bur. Mines, Tech. Paper 510, 1932 (18 with 19 figs.). 23 cm.

LONDON, METEOROLOGICAL OFFICE. The observatories' year book 1930, comprising the meteorological and geophysical results obtained from autographic records and eye observations at the observatories at Lerwick, Aberdeen, Eskdalemuir, Cahirciveen (Valentia Observatory), and Richmond (Kew Observatory), and the results of soundings of the upper atmosphere by means of registering balloons. London, H. M. Stationery Office, 1932 (443). 31 cm.

MARIS, H. B. Seasonal variations in magnetic storms. Phys. Rev., Menasha, Wis., v. 39, No. 3, 1932 (504-514).

MAURITIUS, ROYAL ALFRED OBSERVATORY. Results of magnetical and meteorological observations for the months of September to December, 1930 (new series, v. 16, pts. 9-12). Port Louis, Govt. Press, 1930 (145-218). 34 cm.

MILLER, A. H. Surveys with the torsion balance and the magnetometer in eastern Canada. Toronto, J. R. Astr. Soc. Can., v. 26, No. 1, 1932 (1-16).

MOUNT WILSON OBSERVATORY. Summary of Mount Wilson magnetic observations of sunspots for July to December, 1931. Pub. Astr. Soc. Pacific, San Francisco, Cal., v. 43, 1931 (354-355; 409-411); v. 44, 1932 (57-59).

MURAMOTO, A. On the source of local disturbances of terrestrial magnetism in the vicinity of Seizan-tô on the southern coast of Tyôsen. Hydrogr. Bull., Tokyo, 10th year, No. 11, 1931 (437-447 with 4 maps). [Text in Japanese language.]

Weekly magnetic observations at Zinsen, Taihoku, Otomari, and Palau during 1931. Hydrogr. Bull., Tokyo, 10th year, No. 12, 1931 (504-509). [Text in Japanese language.]

N., H. Magnetic storms and solar activity during 1931. Observatory, London, v. 55, No. 692, 1932 (16-17). [Contains table showing magnetic storms as recorded at Greenwich (Abinger) in 1931.]

NEUMANN, G. Magnetische Untersuchungen bei Berggiesshübel in Sachsen. Beitr. Geophysik, Leipzig, Ergänzungshefte, Bd. 2, Heft 1, 1931 (22-68).

NEW ZEALAND, DEPARTMENT OF LANDS AND SURVEY. Annual report on survey operations for the year ended 31st March 1931. Wellington, W. A. G. Skinner, 1931 (9). 34 cm. [Contains brief report on the Magnetic Observatory, with mean annual values of the magnetic elements for the year 1930 as obtained at the Amberley Substation with equivalent Christchurch values.]

NIPPOLDT, A. Ergebnisse der magnetischen Beobachtungen in Seddin im Jahre 1929. Berlin, Veröff. met. Inst., Nr. 383, 1931 (35 mit 1 Kurventafel und 9 losen Kurvenblättern.). 34 cm.

Eegebnisse der erdmagnetischen Beobachtungen in Seddin im Jahre 1930. Met. Zs., Braunschweig, Bd. 48, Heft 11, 1931 (432-433).

OTTAWA, TOPOGRAPHICAL SURVEY. Annual report of the Topographical Survey for the year ended March 31, 1930. Ottawa, F. A. Acland, 1931 (22 with illus. and 3 maps). [On page 10 is a brief notice of the magnetic declination survey-work executed by the Topographical Survey during the report year.]

Paris, Institut de Physique du Globe. Annales de l'Institut de Physique du Globe de l'Université de Paris et du Bureau Central de Magnétisme Terrestre. Publié par les soins de Ch. Maurain. Tome IX. Paris, Les Presses Universitaires de France, 1931 (iv+206 avec figs. et 4 cartes). 31 cm. [A signaler: L. Eblé—Observations magnétiques faites au Val Joyeux pendant l'année 1929; E. Tabesse—Observations magnétiques faites à l'Observatoire de Nantes pendant l'année 1929; E. Mathias, Ch. Maurain, L. Eblé, et Mlle G. Homery—Anomalies du champ magnétique terrestre en France; E. Mathias—Mesures magnétiques dans les Hautes-Pyrénées, le Gers et la Haute-Garonne; E. Mathias—Mesures magnétiques dans la Haute-Marne, la Côte-d'Or et l'Aube; E. Mathias—Mesures magnétiques dans l'Alliers et le Puy-de-Dôme; E. Mathias—Mesures magnétiques dans la Creuse, la Dordogne et la Haute-Vienne; L. Eblé—Variation séculaire de la distribution des éléments magnétiques: application au tracé des cartes; Mlle G. Homery—Etude sur la variation de la déclinaison en France depuis 1681; E. Salles—La charge électrique portée par l'air; Poisson et Delpeut—Observations magnétiques faites à l'Observatoire de Tananarive (Madagascar) pendant l'année 1929); Mme F. Bayard-Duclaux—Mesures de la conductibilité électrique de l'atmosphère de Paris; J. Chevrier—Reconnaissance magnétique en Syrie. Observations du champ électrique et de la déperdition en Syrie; Principales perturbations magnétiques en 1929 (graphiques obtenus aux enregistreurs du Val Joyeux).]

Pospelow, A. Magnitnaia anomaliia v Novo-Oskolskom raione Ts-Ch-O. Voronezh, Trav. Inst. Rech. Sci., Univ., No. 4, 1930 (4-35). [Magnetic anomaly in the Novo-Oskol region. The anomalous region was found to be from 3 to 5 kilometers wide and about 45 kilometers in length, extending in a NW-SE direction. The question as to the cause of this anomaly as well as of that of Kursk is discussed. Russian text.]

Rio de Janeiro, Observatorio Nacional. Anuario publicado pelo Observatorio Nacional do Rio de Janeiro para o ano de 1932. Ano XLVIII. Rio de Janeiro, Imprensa Nacional, 1931 (xv+408 com mappa). 18 cm. [Contains tables of magnetic declination at various points in Brazil reduced to epoch 1932.0 and an isogonic map of Brazil for September 1922.]

Röstad, A. Ueber magnetische Störungen die an südnorwegischen Nordlichttagen in Potsdam beobachtet wurden. Geofys. Pub., Oslo, v. 9, No. 3, 1931, 30 pp.

Rude, G. T. The determination of the compass-error. A simple method of obtaining compass deviations when the ordinary means are not available. Washington, D. C., U. S. Coast Geod. Surv., Assoc. Field Eng., Bull. No. 4, 1931 (35-37).

Sandoval, R. O. El magnetismo terrestre en México. Mexico, Obs. Astr. Tacubaya, Bull. No. 12, 1931, 26 pp. 31 cm. [Contains compilation of all available values of the magnetic elements in Mexico, arranged alphabetically according to states and territories, and according to increasing latitude under each state or territory.]

Slaucitajs, L. Par magnetisko deklinaciju Rigas apkartne. (Ueber die magnetische Deklination in der Umgebung Rigas.) Daba, Riga, Nr. 3, 1931, 11 pp. 23 cm. [Estnisch mit deutscher Zusammenfassung.]

Sodankylä. Ergebnisse der Beobachtungen des Magnetischen Observatoriums zu Sodankylä im Jahre 1928. Von E. Sucksdorff. (Veröff. Mag. Observatoriums der Finnischen Akad. Wiss., Nr. 15.) Kuopio, Osakeyhtiö Kirjapaino Sanan Valta, 1931 (55 mit 4 Tafeln). 29 cm.

Tacubaya, Observatorio Astronomico Nacional. Anuario del Observatorio Astronomico Nacional de Tacubaya para el año de 1932. Formado bajo la dirección del Ing. Joaquin Gallo. Año 52. Tacubaya, Universidad Nacional de Mexico, 1931 (289). 19 cm. [Contains the mean values of the magnetic declination and horizontal and vertical components for the year 1930, as derived from the magnetograms of the Magnetic Observatory of Teoloyucan, and absolute values of the same elements for the first six months of 1931, as also the values of the magnetic elements obtained at 24 field stations obtained by Observer R. O. Sandoval during a magnetic expedition in southeastern Mexico, November 1930 to April 2, 1931.]

República Mexicana. Líneas de igual declinación, intensidad horizontal, e inclinación para 1932 y sus variaciones anuales. Mexico, Universidad Nacional, Observatorio Astronomico, 50x37 cm. [These three isomagnetic maps of Mexico are on the scale of 1:6,000,000; they show also the lines of equal annual change.]

Tokyo, Central Meteorological Observatory. The annual report of the Kakioka Magnetic Observatory, Japan, for the year 1930. Tokyo, 1931 (55+8 with 23 pls.). 30 cm.

United States Coast and Geodetic Survey. Annual report of the Director, United States Coast and Geodetic Survey to the Secretary of Commerce for the fiscal year ended June 30, 1931. Washington, D. C., Dept. Comm., U. S. Coast Geod. Surv., 1931 (ii+45 with 9 maps). 23 cm. [Contains general account of magnetic and seismological work for the period in question.]

Wilson, J. H. Brunton compass-attachment for measurement of horizontal magnetic intensity. Bull. Amer. Assoc. Petrol. Geol., Tulsa, Okla., v. 15, No. 11, 1931 (1391-1397). [Utilizing the Brunton compass commonly employed by geologists, an attachment has been devised making it possible to measure the horizontal intensity of the Earth's field. The operation of the instrument, theory and derivation of equations, and results of several surveys with the instrument are presented.]

B—Terrestrial and Cosmical Electricity

Appleton, E. V. Polarization of downcoming wireless waves in the Southern Hemisphere. Nature, London, v. 128, Dec. 19, 1931 (1037). [Preliminary announcement of results of investigations on downcoming wireless waves carried out in the Southern Hemisphere (New South Wales) which, as compared with those formerly made in the Northern Hemisphere (England) show a reverse polarization thus indicating, as previously predicted, that the Earth's magnetic field may be the cause of the observed polarization.]

Appleton, E. V., and G. Builder. Wireless echoes of short delay. London, Proc. Phys. Soc., v. 44, No. 241, 1932 (76-87). [An account of a simple method of producing short pulses of radio-frequency energy is given, with notes on its application in the investigation of wireless echoes of short delay. Details of simultaneous visual and photographic methods of delineating such echoes are also described. The discussion of sample records and results serves as a basis for drawing conclusions concerning the relative advantages of the frequency-change and group-retardation methods of investigating the ionized regions of the upper atmosphere.]

Bemis, I. S. Some observations of the behavior of earth currents and their correlation with magnetic disturbances and radio transmission. Proc. Inst. Radio Eng., v. 19, No. 11, 1931 (1931-1947). [This paper presents correlations between the abnormal earth currents noted during magnetic storms and transoceanic radio transmission on both long and short waves as obtained from radio transmission data collected on the telephone circuits operating between New York and London and between New York and Buenos Aires, and earth-current data collected on two Bell System lines extending approximately a hundred miles north and west from New York.]

Bennett, R. D., J. C. Stearns, and A. H. Compton. The constancy of cosmic rays. Phys. Rev., Menasha, Wis., v. 38, No. 8, 1931 (1566).

Boylan, R. K. The mobilities of atmospheric large ions. Dublin, Proc. R. Irish Acad., A, v. 40, No. 4, 1931 (76-85). [The ionization of the air in a well-ventilated room in Dublin was examined with a M'Clelland apparatus. The curves obtained did not show saturation at a voltage corresponding to the mobility of the Langevin ion (.00033). The ionization measured increased by amounts varying from 28 per cent to 200 per cent when sufficient voltage to produce saturation was used. The ionization was also examined with a Zeleny divided-electrode apparatus. Curves obtained with the two methods point to the existence of groups of large ions of mobilities both higher and lower than that of the Langevin ion.]

Cave, C. J. P. Thunder-storm at Stoner Hill, Petersfield, August 5, 1931. London, Q. J. R. Met. Soc., v. 57, 1931 (421). [Brief note regarding a curious lightning-stroke which occurred during the storm in question.]

Chevrier, J. Recherches sur le champ électrique de l'air en Djesireh. Paris, C.-R. Acad. sci., T. 193, No. 17, 1931 (741-742).

Compton, A. H., R. D. Bennett, and J. C. Stearns. Ionization as a function of pressure and temperature. Phys. Rev., Menasha, Wis., v. 38, No. 8, 1931 (1565-1566).

Darrow, K. K. Data and nature of cosmic rays. New York, N. Y., Bell. System Tech. J., v. 11, No. 1, 1932 (148-184). [Contemporary advances in physics, XXIII.]

Dauvillier, A. Synthèse de l'aurore polaire. Paris, C.-R. Acad. sci., T. 193, No. 20, 1931 (946-948).

Sur la théorie de l'aurore polaire. Paris, C.-R. Acad. sci., T. 194, No. 2, 1932 (192-194).

DOUGLAS, C. K. M. Note on the thunder-storms of June 5, 1931. London, Q. J. R. Met. Soc., v. 57, 1931 (470-472).

DUFAY, J. Les bandes d'émission de l'aurore polaire dans le spectre du ciel nocturne. Paris, C.-R. Acad. sci., v. 193, No. 22, 1931 (1106-1108).

EREDIA, F. Sull' elettricità atmosferica. Universo, Firenze, anno 12, Num. 11, 1931 (140-142).

FÖRSTERLING, K., UND H. LASSEN. Die Ionisation der Atmosphäre und die Ausbreitung der kurzen elektrischen Wellen (10-100 m) über die Erde. I, II, und III. Zs. techn. Physik, Leipzig, Jahrg. 12, 1931 (453-469; 502-527).

GOLDIE, A. H. R. The electric field in terrestrial magnetic storms. Edinburgh, Trans. R. Soc., v. 57, Pt. 1, No. 4, 1931 (143-177).

GRABHAM, M. Electrical conditions in stratified clouds. Nature, London, v. 128, Dec. 5, 1931 (969).

GRADENWITZ, A. L'énigme de l'aurore boréale. Théories scandinaves et expériences allemandes. Nature, Paris, 59e année, No. 2871, 1931 (529-530).

GREENWICH, ROYAL OBSERVATORY. Results of the magnetic and meteorological observations made at the Abinger magnetic station, Surrey, and the Royal Observatory, Greenwich, respectively, in the year 1929, under the direction of Sir Frank Dyson, Astronomer Royal. London, His Majesty's Stationery Office, 1930 (101 with 10 pls.). 30 cm.

HARANG, L. Filteraufnahmen von Polarlicht. Zs. Geophysik, Braunschweig, Jahrg. 7, Heft 7/8, 1931 (324-336). [Die Intensitätsvariation in Grün und Violett in einzelnen Polarlichtern wird mittels Filteraufnahmen studiert.]

HESS, V. F. Die Station für Untrastrahlungforschung auf dem Hafelekar (2300 m) bei Innsbruck. Forsch. u. Fortschr., Berlin, Jahrg. 7, Nr. 31, 1931 (410).

KNAEBEL, C. H. Observation and deduction applicable to measurements of electrical resistivity of large volumes of earth in place. Houghton, Mich., Bull. Coll. Min. Tech., v. 5, No. 2, 1932 (31 with 4 pls.). 23 cm.

KOLHÖRSTER, W., UND L. TUWIM. Die spezifische Ionisation der Höhenstrahlung. Naturw., Berlin, Jahrg. 19, Heft 45, 1931 (917).

Die spezifische Ionisation der Höhenstrahlung. Zs. Physik, Berlin, Bd. 73, Heft 1/2, 1931 (130-136).

IMBRECQ, J. Sur une foudre globulaire à éclatements multiples. Paris, C.-R. Acad. sci., T. 193, No. 20, 1931 (949). [Brief description of a case of ball lightning observed in Paris in June 1914.]

ISRAËL, H. Luftelektrische Messungen im Hochgebirge und ihre mögliche bioklimatische Bedeutung. Beitr. Geophysik, Leipzig, Bd. 34, 1931 (164-193). [Atmospheric-electric determinations at two mountain stations are communicated for the purpose of throwing light on the relations between atmospheric electricity and bioclimatical factors. Positive and negative large and small ions and condensation-nuclei were measured. There is much likelihood that the ionization of the atmosphere is not connected with "Föhnkrankheit" (Föhn sickness). It appears, however, at one of the stations, Badgastein, to be an essential climatic factor which seems worthy of a more detailed investigation.]

LUTZ, C. W. Geräte zur Messung und Aufzeichnung des luftelektrischen Spannungsgefälles. Beitr. Geophysik, Leipzig, Bd. 31, Heft 4, 1931 (398-425). [Zur absoluten Messung des luftelektrischen Spannungsgefälles wird eine neue, von konstanten Fehlern freie Aufstellungsart für radioaktive Potentialsonden angegeben, die im künstlichen und natürlichen elektrischen Felde eingehend geprüft wurde. Ferner wird ein vereinfachtes kleines Saitenelektrometer beschrieben, das ausser zum Gebrauch im Laboratorium besonders auch zu luftelektrischen Messungen im Freien, im Flugzeug und Fallschirm geeignet ist, und hierzu ein kleiner, leicht tragbarer photographischer Registrierapparat angegeben, der auch für andere Saiten—sowie für Spiegelinstrumente verwendet werden kann.]

MATHIAS, E. Sur les éclairs fulgurants ascendants. Paris, C.-R. Acad. sci., T. 193, No. 20, 1931 (909-912).

Sur les éclairs en chapelet avec traits. Paris, C.-R. Acad. sci., T. 193, No. 26, 1931 (1375-1377).

Variation de la tension superficielle de la matière fulminante en fonction de la température et du poids moléculaire. Paris, C.-R. Acad. sci., T. 194, No. 5, 1932 (413-416).

MELANDER, G. Is it possible to study directly the nature of the auroral rays? Helsingfors, Ann. Soc. Sc. Fenn., A, v. 33, No. 12, 1931, 5 pp.

MESSERSCHMIDT, W., UND W. S. PFORTE. Ueber den Luftdruckkoeffizienten der harten Ultrastrahlung. Zs. Physik, Berlin, Bd. 73, Heft 9/10, 1932 (677-680). [Der Luftdruckkoeffizient der harten Ultrastrahlung (allseitig 10 cm Bleiabschirmung) ist im Mittelwert während der Messdauer eines halben Jahres sehr konstant, ebenfalls die Strahlungsintensität, reduziert auf einen Barometerstand von 750 mm Hg. Bei schnell vorüberziehenden Barometertiefs zeigen sich Abweichungen vom mittleren Luftdruckkoeffizienten.]

MILLIKAN, R. A. Further experiments on the uniformity of distribution of the cosmic radiation. Phys. Rev., Menasha, Wis., v. 39, No. 3, 1932 (391-396). [The author draws the conclusion from the whole set of observations that within the limits of his own observational uncertainty, which has now been reduced to about a third of a percent, the Sun has no direct influence upon the intensity of the cosmic rays.]

Cosmic-ray ionization and electroscope-constants as a function of pressure. Phys. Rev., Menasha, Wis., v. 39, No. 3, 1932 (397-402).

MOTT-SMITH, L. M. On an attempt to deflect magnetically the cosmic-ray corpuscles. Phys. Rev., Menasha, Wis., v. 39, No. 3, 1932 (403-414). [Reports the results of an experimental attempt magnetically to deviate the high-energy corpuscles associated with the cosmic radiation, With a magnetic analyser involving the use of Geiger-Müller electron counters and the magnetic field in the interior of a magnetized iron bar, it is found that no deviation of the corpuscles which cause the simultaneous discharges of the counters occurs. Calculations of the sensitivity indicates that an observable deviation would have been produced if the corpuscles were electrons of energy 2×10^9 *e*-volts or less or protons of energy 10^9 *e*-volts or less. The difficulties involved in explaining this result are discussed and various possible interpretations are presented.

MOTT-SMITH, L. M., AND G. L. LOCHER. A new experiment bearing on cosmic-ray phenomena. Phys. Rev., Menasha, Wis., v. 38, No. 8, 1931 (1399-1408).

OSLO, NORWEGISCHES METEOROLOGISCHES INSTITUTl Jahrbuch des Norwegischen Meteorologischen Instituts für 1930. Oslo, Gröndahl und Sön, 1931 (xiv+176). 33 cm. [Contains values of electrical potential-gradient and conductivity at the Aas Meteorological Observatory.]

PFORTE, W. S. Zur Struktur der Ultrastrahlung. II. Vergleichende Messungen an zwei Hochdruckionisations-kammern. Zs. Physik, Berlin, Bd. 72, Heft 7/8, 1931 (511-527).

POSPELOW, A., UND M. SKRJABIN. Beobachtungen über die atmosphärische Elektrizität in Woronesch im Jahre 1929. Voroneszh, Trav. Inst. Rech. Sci. Univ., No. 4, 1930 (37-41). [Potential gradient only was observed. Russian text.]

PUIG, I. Le gradient de potentiel atmosphérique à l'Observatoire de l'Ebre (1910-1930). Beitr. Geophysik, Leipzig, Bd. 33, 1931 (338-350).

RAKSHIT, H. On an estimation of the height of the Heaviside layer in Bengal. Phil. Mag., London, v. 12, No. 80, 1931 (897-907).

RAMANATHAN, K. R. The zodiacal light and the luminosity of the night sky. Nature, London, v. 129, Feb. 20, 1932 (280).

RIES. Perlschnurblitz? Met. Zs., Braunschweig, Bd. 48, Heft 12, 1931 (509). [Description of a single observation.]

ROMAN, I. How to compute tables for determining electrical resistivity of underlying beds and their application to geophysical problems. Washington, D. C., U. S. Bur. Mines, Tech. Paper 502, 1931, 44 pp. 23 cm.

ROSE, D. C. The ionization of the atmosphere measured from flying aircraft. Ottawa, Can. J. Res., v. 5, 1931 (625-635). [The Gerdien type of atmospheric ionization measuring apparatus was attached to a cabin aeroplane so that the state of ionization of the atmosphere could be studied. The limitations of the apparatus for aeroplane use are discussed. Measurements were taken from ground level to heights of 15,000 ft. The results are plotted in number of ions per cc. (separate curves for positive and negative) at different altitudes. The results indicate that at the cloud level there is an abnormal excess of small positive ions and a minimum in the excess of positive ions over negative ions from 4,000-6,000 ft. higher. This does not include large ions such as charged water drops or dust particles. The observations were taken in regions free from clouds.]

ROSSI, B. Absorptionsmessungen der durchdringenden Korpuskularstrahlung in einem Meter Blei. Naturw., Berlin, Jahrg. 20, Heft 4, 1932 (65).

SCHINDLER, H. Uebergangseffekte bei der Ultrastrahlung. Zs. Physik, Berlin, Bd. 72, Heft 9/10, 1931 (625-657). [Gekürzte Königsberger Dissertation.]

SCHMAUSS, A. Koagulation durch Blitz. Met. Zs., Braunschweig, Bd. 48, Heft 12, 1931 (508). [Brief note regarding the sudden transformation of a bank of fog or low-lying cloud into rain-drops through a lightning-stroke.]

SCHONLAND, B. F. J., AND T. E. ALLIBONE. Branching of lightning. Nature, London, v. 128, Nov. 7, 1931 (794-795). Brief comment by J. L. P. Macnair, *ibidem*, Dec. 5, 1931 (969).

SHEPPARD, P. A. Character of atmospheric ionisation. Nature, London, v. 129, Jan. 30, 1932 (169).

SPILSBURY, R. S. J. Duration and magnitude of a lightning-discharge. Nature, London, v. 128, Nov. 21, 1931 (872).

STÖRMER, C. Ueber die Probleme des Polarlichtes. Leipzig, Akademische Verlagsgesellschaft, m. b. H., 1931 (1-86 mit Abb.). 23 cm. [Sonderdruck aus Ergebnisse der kosmischen Physik, Bd. 1.]

SÜRING, R. Ergebnisse der meteorologischen Beobachtungen in Potsdam im Jahre 1930. Berlin, Veröff. met. Inst., Nr. 384, 1931 (iv+88). 34 cm. [On pp. 72-83, are given the hourly values of the atmospheric-electric potential gradient for 1930, and on page 88 the means of the quiet days.]

TERADA, T. Earthquake and thunder-storm. Bull. Earthquake Res. Inst., Tokyo, v. 9, Pt. 4, 1931 (387-397). [Statistical inquiry into the possibility of a relation between thunder-storms and earthquakes. English text with Japanese abstract.]

VEGARD, L. Wave-length of the green auroral line determined by the interferometer. Nature, London, v. 129, Jan. 2, 1932 (23).

WIESE, W. Meteorological observations of the Sedov Polar Expedition. Vol. I. Observations at Foka Bay, Novaya Zemlya, 1912-1913. Leningrad, Arctic Institute, 1931 (252). 31 cm. [Materials for the study of the arctic, No. 1. Contains, in addition to meteorological results, account of the auroral observations, with tables showing numbers of days with aurora, and sketches showing the diurnal and annual period of the aurora at Foka Bay. Text in Russian with titles of chapters and legends of tables, etc., also in English.]

WÖLCKEN, K. Ueber Messungen und Registrierungen der Ultrastrahlung. (Durchdringende Höhenstrahlung.) Göttingen, Druck der Dieterichschen Universitäts-Buchdruckerei (W. Fr. Kaestner), 1931 (26). 23 cm. [Inaugural-Dissertation, Göttingen, 1931. Die Dissertation gliedert sich in zwei Teile: (1) Messungen und Registrierungen mit der Kolhörsterschen Ionisationskammer; (2) Messungen und Registrierungen mit Elektronenzählrohren.]

C—Miscellaneous

ALIVERTI, G. Nuovo metodo per determinare quantitativamente il contenuto in sostanze radioattive dell'aria atmosferica. Estratto: Nuova Cimento, Bologna, Anno 8, N. 7, 1931, 14 pp.

AMES, J. S. Certain aspects of Henry's experiments on electromagnetic induction. J. Acad. Sci., Washington, D. C., v. 21, No. 21, 1931 (493-503).

AUSTIN, L. W. Solar activity and radiotelegraphy. New York, N. Y., Proc. Inst. Radio Eng., v. 20, No. 2, 1932 (280-285). [This report shows that the relationships are closer at short wave-lengths than at long; that the effect of magnetic storms, which are assumed to be due to solar action, is, in general, to weaken night signals at all wave-lengths and in the medium and long-wave ranges to strengthen day signals. Curves are given showing that there is a direct correlation between the yearly averages of long waves, daylight transatlantic signals, sun-spot numbers, and magnetic activity (1915-1930), a direct correlation between signals and magnetic-activity averages by months (1924-1930) and an inverse correlation between sunspots and atmospheric-disturbance averages by years (1918-1930).]

BANGKOK, ROYAL SURVEY DEPARTMENT. Report on the operations of the Royal Survey Department, Ministry of War, for the year 1929-30. Bangkok, Daily Mail Press, 1931 (50 with 2 pls. and 8 index maps). [No magnetic observations were made during the report period.]

BEHOUNEK, F., UND W. SANTHOLZER. Ueber die Radioaktivität der Gesteine aus dem Uranpecherzbergbaurevier von St. Joachimsthal in Böhmen. Beitr. Geophysik, Leipzig, Bd. 33, 1931 (60-69).

Breitfuss, L. Der sibirische Seeweg und seine physikalischen Verhältnisse. Arktis, Gotha, Jahrg. 4, 1931 (27-31; 73-109). [On pp. 92-94 is a brief discussion of terrestrial magnetism of the region accompanied by two isogonic maps.]

Brillouin, M. Développement en fonctions harmoniques sur la sphère d'une fonction dont la valeur est donnée en chaque point du rivage continental. Représentation conforme. Paris, C.-R. Acad. sci., T. 193, No. 26, 1931 (1360-1364).

British Association for the Advancement of Science. Problems of the Earth's crust. London, Geog. J., v. 78, 1931 (433-455; 536-544). [Discussion in Section E (Geography) of the British Association, September 28, 1931, by various specialists, of the present state of knowledge and speculation in regard to the major features of the lithosphere of the Earth.]

Chalonge, D. Sur la répartition de l'ozone dans l'atmosphère terrestre. J. Physique et Le Radium, Paris, Ser. 7, T. 3, No. 1, 1932 (21-42).

Conrad, V., und L. Weickmann. Ergebnisse der kosmischen Physik. Herausgegeben von V. Conrad und L. Weickmann. Erster Band. Leipzig, Akademische Verlagsgesellschaft m. b. H., 1931 (xi+448 mit 243 Figuren). [Enthält: Uuber die Probleme des Polarlichtes, von Carl Störmer; Der Barometereffekt der Höhenstrahlung, und Absorptionskoeffizienten der Höhenstrahlung, von W. Kolhörster und L. Tuwim; Das atmosphärische Ozon, von F. W. Paul Götz, usw. See review in this number of the Journal.]

Coolidge, W. D., L. E. Dempster, and H. E. Tanis. High voltage cathode ray and X-ray tubes and their operation. Physics, Menasha, Wis., v. 1, No. 4, 1931 (230-244).

Debenham, F. International polar research. Discovery, London, v. 13, No. 145, 1932 (14-16). [Brief popular outline of work proposed for the second International Polar Year 1932-1933, with special reference to British participation.]

Einstein, A. Gravitational and electric fields. Science, New York, N. Y., N. S., v. 71, Oct. 30, 1931 (438-439). [Preliminary statement regarding forthcoming work, in collaboration with Dr. Walter Mayer, on the "Unitary theory of gravitation and electricity."]

Ellsworth, L., and E. H. Smith. Report of the preliminary results of the Aeroarctic Expedition with "Graf Zeppelin," 1931. Geog. Rev., New York, N. Y., v. 22, No. 1, 1932 (61-82 with map).

Fabiani, R. Esplorazione geofisica regionale della Sicilia con brevi cenni sui metodi e sugli strumenti di recerca. Universo, Firenze, anno 12, Num. 10, 1931 (525-551). [L'A., premesse alcune nozioni sui metodi e sugli strumenti impiegati nelle ricerche gravimetriche e geomagnetiche, con speciale riferimento alla nuova esplorazione geofisica regionale della Sicilia da lui promossa, informa sui criteri generali seguiti nella distribuzione delle stazioni e sulla finalità propostasi nel promuovere la esplorazione stessa e accenna infine a qualche risulto che, pure allo stato attuale dei calcoli, non ancora ultimati, è andato delineandosi.]

Fleming, J. A. The proposed second International Polar Year, 1932-1933. Geog. Rev., New York, N. Y., v. 22, No. 1, 1932 (131-134).

Gall, D. C. Some experiments relating to geophysical prospecting. With an introduction by A. Broughton Edge. London, J. Sci. Instr., v. 8, No. 10, 1931 (305-313 with 8 figs.). [Description of the "equiquadrature method" of prospecting for conductive bodies.]

Gilliland, T. R., and G. W. Kenrick. Preliminary note on an automatic recorder giving a continuous height record of the Kennelly-Heaviside layer. Washington, D. C., Bur. Stan. J. Res., v. 7, No. 5, 1931 (783-789 with 9 figs. and 1 table).

Gilliland, T. R., G. W. Kenrick, and K. A. Norton. Investigations of Kennelly-Heaviside layer heights for frequencies between 1600 and 8650 kilocycles per second. New York, N. Y., Proc. Inst. Radio Eng., v. 20, No. 2, 1932 (286-309).

Glanville, W. E. Zodiacal light notes. Pop. Astr., Northfield, Minn., v. 40, No. 1, 1932 (61-63).

Hale, G. E. Signals from the stars. New York, Charles Scribner's Sons, 1931 (xx+138 with illus). 20 cm. Price $2.00. [This small book, of a popular nature, is based on articles, recently published in somewhat different form in various magazines. Its four chapters are entitled: The possibilities of large telescopes; Exploring the solar atmosphere; Signals from the Sun; Building the 200-inch telescope. While primarily dealing with the possibilities of very large telescopes, interesting opportunities recently opened to small instruments are also emphasized.]

HEILAND, C. A., AND D. WANTLAND. A selected list of books and references on geophysical prospecting. Q. Colo. School Mines, Golden, Colo., v. 26, No. 3, 1931, 24 pp. [This list was prepared primarily as a supplement to classroom instruction and contains about 200 items, among which are included those on magnetic and electric methods. Publications in English are listed wherever possible and preference is given to the more recent articles.]

HEYWOOD, H. B. On finite sequences of real numbers. London, Proc. R. Soc., A, v. 134, 1931 (486-501). [Mathematical theorems bearing on partial correlations.]

HOBECKER, O. Ueber die Polarisation des magnetischen Vektors beim Peilempfang. Ann. Hydrogr., Berlin, Jahrg. 59, Heft 8, 1931 (293-304).

HOGG, A. R. Aitken condensation-nuclei. Nature, London, v. 128, Nov. 28, 1931 (908).

HOOTMAN, J. A. Determination of the radioactivity of natural waters and some results for flowing artesian wells. Amer. J. Sci., New Haven, Conn., v. 22, No. 131, 1931 (453-463).

IMAMITI, S. Ein Experiment zur Bestimmung des Polabstandes eines Stabmagnets. Ann. Rep. Kakioka Mag. Obs., 1930, Tokyo, 1931, 8 pp.

INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS. Fifth Assembly of the International Research Council and the First Assembly of the International Council of Scientific Unions held at Brussels July 11th, 1931. Report of proceedings, edited by Sir Henry Lyons, General Secretary. London, Harrison and Sons, Ltd., 1931 (iii+105). 25 cm.

INTERNATIONAL RESEARCH COUNCIL. Third report of the Commission appointed to further the study of Solar and Terrestrial Relationships. London, Percy Lund, Humphries and Co., Ltd., 1931 (v+132). 22 cm.

KOHL-LARSEN, L. Die Arktisfahrt des "Graf Zeppelin." Berlin, Union Deutsche Verlagsgesellschaft, 1931 (202 mit 55 Abb. und 1 Karte). 21 cm. [Herausgegeben im Auftrage des Internationalen Gesellschaft zur Erforschung der Arktis mit Luftfahrzeugen (Aeroarctic). Mit eimem Vorwort von Dr. Hugo Eckener.]

LEE, F. W. A comment upon present-day applied geophysics. Washington, D. C., Dept. Comm., U. S. Bur. Mines, Inf. Cir. 6496, 1931, 5 pp. 27 cm.

LONDON, DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH. Report of the Radio Research Board for the period ended 31st December 1930. London, H. M. Stationery Office, 1931 (iii+90). 24 cm. [Contains reviews of investigations in progress among which are the following: Propagation of waves, directional wireless, atmospherics, study of aerials for transmission and reception, electrical measurements at radio frequencies.]

MAURAIN, CH. L'étude du sous-sol par les méthodes géophysiques. Recherches et Inventions, Bellevue, v. 12, No. 198, 1931 (65-73).

MILLIKAN, R. A. Contribution to a British Association discussion on the evolution of the universe. Nature, London, v. 128, Oct. 24, 1931 (709-715). [An outline of the present status of the development of our knowledge of cosmic radiation with indication of the influence of this knowledge upon the theories of stellar evolution.]

MÖGEL, H. Ueber die Beziehungen zwischen Empfangs-Störungen bei Kurzwellen und den Störungen des magnetischen Feldes der Erde. Telefunken-Zeitung, Jahrg. 11, Nr. 56, 1930 (14-31).

NEW ZEALAND. Eleventh annual report of the Government of New Zealand on the administration of the mandated territory of Western Samoa for the year ended the 31st March 1931. Wellington, W. A. G. Skinner, Govt. Printer, 1931 (34 with map). 34 cm. [Contains very brief note on the magnetic and electric work at the Apia Observatory, but no values are given.]

NIPPOLDT, A. Tagung der Internationalen Kommission für Erdmagnetismus und Luftelektrizität und der Internationalen Kommission für das Polarjahr 1932-1933 vom 21. bis 26. September in Innsbruck. Naturw., Berlin, Jahrg. 20, Heft 1, 1932 (23-24).

PAUL, J. H. The last cruise of the *Carnegie*. With a foreword by John A. Fleming. Baltimore, Williams and Wilkins Co., 1932 (xvii+331 with 198 illus.). 24 cm. [A popular account of the non-magnetic ship *Carnegie*. The vessel, work, and equipment are described and a detailed narrative is given of her seventh cruise, which came to an abrupt and fatal end in the harbor of Apia, Samoa, on November 29, 1929, when the unique vessel was destroyed by an explosion bringing death to her captain.]

Picht, J. Ueber Lichtschreiber-Registrierapparate. Zs. Instrumentenk., Berlin Jahrg. 51, Heft 11, 1931 (574-578).

Priebsch, J. Die Höhenverteilung radioaktiver Stoffe in der freien Luft. Met. Zs., Braunschweig, Bd. 49, Heft 2, 1932 (80-81).

Puig, I. El Año International Polar 1932-1933. Ibérica, Barcelona, Año 18, Núm. 899, 1931 (250-254).

Robertson, J. M. A simple harmonic continuous calculating machine. Phil. Mag., London, v. 13, No. 84, 1932 (413-419 with 1 pl.). [A mechanical method is described for summing single, double, and triple Fourier series, and solving sets of linear and certain transcendental simultaneous equations.]

Sverdrup, H. U. Die wissenschaftlichen Arbeiten auf der Wilkins-Ellsworth-Expedition 1931. Arktis, Gotha, Jahrg. 4, Heft 3/4, 1931 (49-50 mit 1 Karte).

United States Naval Observatory. Annual report of the Naval Observatory for the fiscal year 1931. Washington, D. C., Govt. Print. Off., 1931 (23). 23 cm. [Report of Compass Division, pp. 5-7.]

Vegard, L. Die Korona der Erde und Sonne und ihre Beziehung zu kosmischen Erscheinungen. Beitr. Geophysik, Leipzig, Bd. 32, 1931 (288-300).

Vigneron, A. Les méthodes géophysiques de prospection du sous-sol. Nature, Paris, 59e année, No. 2867, 1931 (341-349).

Wigand, A., und E. Frankenberger. Die elektrostatische Stabilisierung von Nebel und Wolken und die Niederschlagsbildung. Ann. Hydrogr., Berlin, Jahrg. 59, 1931 (353-363; 398-403).

NOTICE